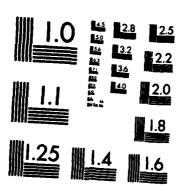
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PREPARED UNDER

MDA 903-81-C-0281

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February to October 1982

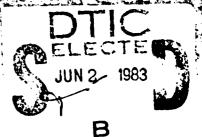


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TITLE

X-Wing 25 Foot Diameter Lockheed Model Rotary Wing Whirl Test Report

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MDA 903-81-C-0281

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PERIOD COVERED

February to October 1982

THIS DOCUMENT IS APPLICABLE TO THE FOLLOWING AIRCRAFT MODEL(S) AND CONTRACT(S):

MODEL X-Wing . CONTRACT MDA 903-81-C-0281

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В



CONTROL DESCRIPTION ARCHITICAL PROPERTY.

SUMMARY

The Lockheed 25 foot diameter X-Wing model rotor's operating envelope was successfully expanded to levels that more closely represent the expected operating environment for the full scale X-Wing rotor. This gives added confidence in the viability of full scale rotor.

Parameter	Previous Maximum Level	Present Maximum Level
Thrust	3500 lb.	9000 1Ъ.
Thrust Coefficient (CT/σ)	.07	. 18
Total Figure of Merit	.59	.78
Torque	55,000 inlb	160,000 inlb
Momentum Coeff. $(C\mu/\sigma)$.0027	.0077
Blade Root Pressure Ratio	1.5	2.06
Collective Pitch	+3°	+8.3°
Tip Speed	529 ft/sec	650 ft/sec

The benefit from collective pitch in reducing the compressor power requirements for a given thrust is non-linear, and is significantly reduced for collective levels above 4 degrees.

The analytical performance programs CRUISE 4 and CCHAP showed good correlation with the test data, except for the pneumatic parameters where they both represented the correct trends, but underestimated the magnitudes. At blade pressure ratios above 1.7 the coanda performance degraded as the slot exit velocity became sonic. This was evident by a negative slope change in the thrust/pressure ratio relationship. However, this degradation was not severe enough to cause a decrease in the thrust level, (just a slope change).

Blown tips showed no net improvement in the total power requirements. The decrease in shaft power due to reduced drag was matched by an increase in compressor power.

Leading edge taping lowered the shaft power requirements. The net benefit ranged from 5 to 15% reduction in torque (dependent on blade angle) and from 4 to 10% improvement in shaft figure of merit. Control power was insufficient to investigate control response due to the large nominal valve opening. To achieve the blade pressure ratios desired for the high thrust performance, the mean valve area was fixed at 80% open. This reduced the amount of the Δp available for control inputs.

The scope of the track and balance efforts was insufficient to minimize the 1P head moments. However, the effect of these moments on the rotor performance parameters is small. The need for tools to independently control individual blade pneumatic performance is very strong.

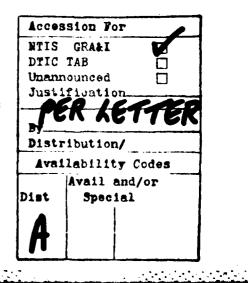
Vibratory thrust levels were consistently between 15-30% of the median. The predominant frequency was 8 (number of valves) per rev. These vertical g levels need serious consideration from both ride comfort and structural standpoints.



TABLE OF CONTENTS

		Page
	SUMMARY	í
1.0	SCOPE	1.0
1.1	Purpose	1.0
1.2	Background	1.0
1.3	Location	1.1
1.4	Witnesses	1.1
2.0	REFERENCES	2.0
2.1	Contract	2.0
2.2	Drawings	2.0
2.3	Reports	2.0
3.0	PROCEDURE	3.0
3.1	Facility Description	3.0
3.2	Model Limitations	3.1
3.3	Instrumentation	3.1
3.4	Test Conduct	3.1
3.5	Derived Parameters Equations	3.4
4.0	RESULTS	4.0
4.1	General Performance and Analytical Correlation	4.0
4.1.1	Standard Rotor Parameters	4.5
4.1.2	Pneumatic Response (Pressures,	
	Flows, Slot Stiffness)	4.7
4.1.3	Blade Bending Response	4.7
4.2	Vibration/Acoustics	4.8
4.3	Balance Efforts	4.10
4.3.1	Duct Area Reduction	4.11
4.3.2	Blade Angle Changes	4.12
4.3.3	Partial Trailing Edge Taping	4.12
4.4	Miscellaneous Effects	4.14
4.4.1	Tips Blocked	4.14
4.4.2	Leading Edges Taped	4.14
5.0	CONCLUSIONS AND RECOMMENDATIONS	5.0







.O SCOPE

1.1 Purpose

This test on the Lockheed designed 25 foot diameter X-Wing rotor had four purposes:

- (a) to expand the operating envelope to tip speeds of 700 ft/sec. and CT/σ of .20 (by increasing θ. to 8.5°, BPR to 2.1)
- (b) (2) to investigate track and balance sensitivities.
- (c)(3)to evaluate the control system response characteristics at the higher disc loading.
- (d)(+)to correlate CCHAP and CRUISE 4 analytical predictions with test data,

(e)(5)to evaluate downwash on the close proximity fuselage

This report will comment on the first four items; item (e) will be addressed by Boeing Vertol.

1.2 Background

This rotor design concept employs circulation control of lift as opposed to mechanical control as on conventional helicopters. Compressed air is ducted and modulated to each blade through a common plenum, as shown in Figure 1.2.1. Valving in the plenum provides both cyclic and collective control to the rotor. A mechanical collective system augments this pneumatic system. The air exits the trailing (or leading) edge of the blade through a flexible slot as shown in Figure 1.2.2. This high velocity stream adheres to the coanda surface, increases the airfoil circulation, and thus the lift on the blade as shown in Figure 1.2.3.

The X-wing aircraft concept involves a two part flight regime. Below a certain forward airspeed the aircraft would operate as a typical rotary wing vehicle. Above this airspeed the rotor would be braked to a stop and would fly fixed wing as shown in Figure 1.2.4. This twenty five foot diameter rotor was tested previously on the Lockheed whirl stand and also in the Ames 40'x80' wind tunnel. This testing was reported in Reference 2.2.1.

The present testing was proposed when it became apparent that an operational X-wing rotor design would require higher tip speeds and disc loadings than those obtained during the previous testing with this model.

Lockheed Report 30254 Reference 2.2.4 contains data, plotted and in tabular format, which formed the basis for this report. Extensive use of the plotted data, Figures, and Tables from Lockheed Report 30254 was made in preparation of this report; where used without alteration they are so indicated.



1.3 Location and Date

Test was conducted at the Lockheed California Co., Rye Canyon plant, Valencia, California during February, March, and April 1982.

1.4 Witnesses

The test was witnessed by the following:

F. Ebert	Sikorsky Aircraft
L. Kingston	Sikorsky Aircraft
P. Perschbache	r Sikorsky Aircraft
M. Potash	Sikorsky Aircraft
J. Keller	Boeing Vertol
R. Williams	DARPA
K. Reader	DTNSRDC
G. Smith	DTNSRDC
F. Dewan	Lockheed
D. Oliva	Lockheed
A. Potthast	Lockheed
I. Sachs	Lockheed
J. Healy	Lockheed

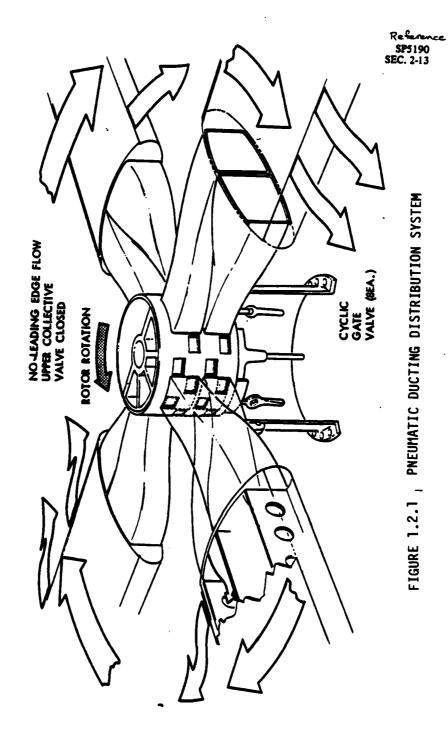


FIGURE 1.2.1 , PNEUMATIC DUCTING DISTRIBUTION SYSTEM

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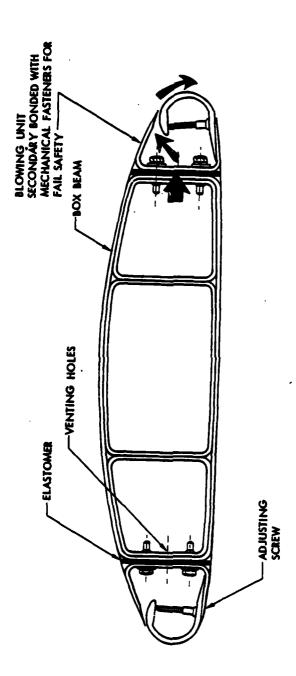


FIGURE 1.2.2 BLADE CROSS SECTION AIR FLOW DIAGRAM

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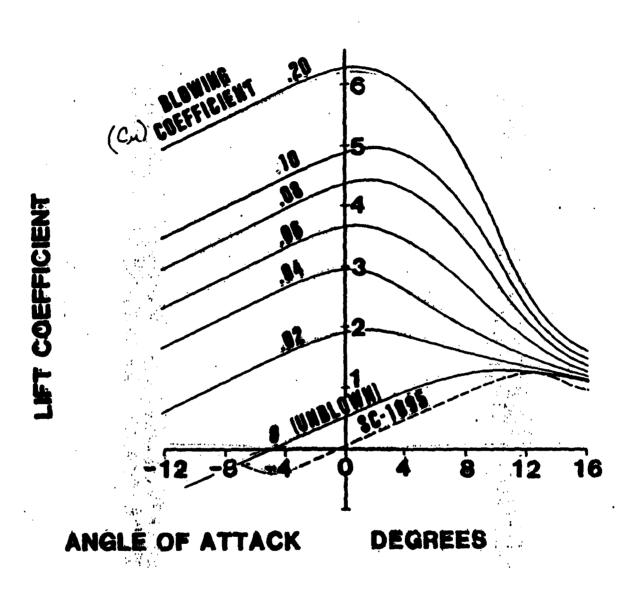
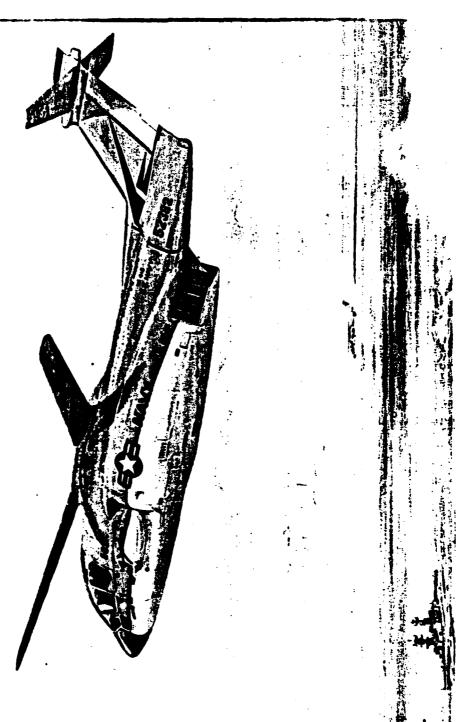


FIGURE 1.2.3.

TYPICAL DIRCULATION CONTROL AIRFOIL CHARACTERISTICS



X-WING AIRCRAFT (ARTIST'S CONCEPT) IN FIXED WING FLIGHT FIGURE 1.2.4

1.5

PAGE



- 2.0 REFERENCES
- 2.1 Contract

MDA 903-81-C-0281 Mod. PO 0002

- 2.2 Reports
- 2.2.1 Lockheed DARPA/DTNSRDC Report SP 5190 "X-Wing Full Scale Wind Tunnel Test Find Report" October 1980
- 2.2.2 Lockheed Report 29838 "Proposal for Tests of the 25-Foot Diameter X-Wing Rotor System at Lockheed-California Rye Canyon Facility" April 1981
- 2.2.3 Sikorsky Engineering Report 51071 "X-Wing, 25-Foot Diameter Lockheed Model Rotary Wind, Whirl Test Plan" October 1981
- 2.2.4 Lockheed Report 30254/DTNSRDC-ASED-CR-2-82, "Data Compilation Report for the 25-Foot Diameter X-wing Module Whirl Test" August 1982
- 2.2.5 Sikorsky Engineering Report 510070, "X-Wing Blade Pneumodynamic and Structural Test Report", Appendix C, "Rotating Plenum and Blade Slot Test", November 1982.
- 2.3 Letters

- 2.3.1 To X-Wing Project File from Gary Smith (DTNSRDC) dated 9 September 1982 "Cruise 4 Hover Predictions for the Whirl Tower Test".
- 2.3.2 Sikorsky Engineering Letter-6268 to K. Reader (DTNSRDC) from L. Kingston (Sikorsky Aircraft) dated 16 November 1981 "CCHAP Prediction of X-Wing Hover Performance"



3.0 PROCEDURE

3.1 Facility

The Lockheed Rye Canyon whirl stand is shown in Figure 3.1.1. The tower is situated in the center of an earthen bowl whose dimensions are detailed in the Figure 3.1.2 topographical map. The stand was modified as shown in Figure 3.1.3 to raise the attachment point of the X-wing module an additional 1/2 rotor diameter above the previous mount to minimize tower ground effects.

The X-Wing module used in the previous whirl and wind tunnel tests was modified in the following manner:

- (a) Compressed air was supplied from a remote station and ducted to the stand and up the tower as shown schematically in Figure 3.1.4. Formerly the module contained a compressor which supplied the rotor pneumatic requirements. The compressed air supply lines were sized to 550 PSIG at 15 lb/sec. A dump valve located near the module allowed the investigation of unpowered, negative plenum gage pressure, rotor regimes.
- (b) The mechanical collective control system was rerigged to provide +collective (θ C) angles from 0° to 8.5°.
- (c) Due to the failure of the pneumatic collective actuator, the mean · valve position (area) was fixed at 80% open to allow maximum flow area for the higher pressure ratio testing.
- (d) The rotor input shaft was redesigned to transmit higher shaft torques.
- (e) The module fuselage was altered to simulate a larger body, closer to the rotor plane. A crown was placed on the fuselage as shown in Figure 3.1.5; detail dimensions are shown in Figure 3.1.6.
- (f) A higher speed, higher shaft power rotor drive was installed. This system is schematically shown in Figure 3.1.7 and photographed in Figure 3.1.8. This system's capabilities are 160,000 in-lb at 496 rpm (650 ft/sec. @ blade tip).



3.2 Model Limitations

The limitations on control and power inputs to the model are as follows:

Parameter	Maximum Range	Notes
$\theta_{\mathbf{c}}$	0 to +8.5 degrees	max travel
PRB	2.1	above 1.7 with caution, slot lip strength
Shaft Speed	496 RPM	blade tip retention strength
Shaft Torque	160,000 in-lb	shaft static strength
Head Moment	See Figure 3.2.1	blade root end separa- tion/retention bolt strength

The 700 ft/sec. conditions were eliminated due to concern for the blade tip retention structure which is not visually inspectable.

3.3 <u>Instrumentation</u>

A list of the measured parameters is given in Table 3.3.1. These measurements were machine recorded. In addition a number of measurements were recorded manually from gages, oscilloscopes, thermocouples, etc. These measurements are listed in Table 3.3.2.

The blade bending/load instrumentation diagram is presented in Figure 3.3.1. The blade pressure/slot deflection diagram is presented in Figure 3.3.2. A detail of a typical blade coanda measurement setup is presented in Figure 3.3.3 and photo of the setup is shown in Figure 3.3.4. The airflow measurements system at the root of the #1 blade is presented in Figure 3.3.5. The tip airflow measurement system is presented in Figure 3.3.6.

3.4 Test Conduct

Tests consisted of various combinations of the following parameters:

- Rotor tip speeds of 529, 550, 600, and 650 ft/sec.
- Blowing pressure ratios at the blade root venturi of 1.0 thru
 2.1.
- Collective blade angles of 0° thru 8.5°.



Test points are summarized in Table 3.4.1. The first series of tests (Run Cards 1 thru 13) was conducted to obtain a satisfactory track and balance of the rotor system. The basic track and balance was attempted by pitch link adjustments and the positioning of the blade root gates on the trailing edge of the blade which regulate the air flow to the blades. The trailing edge slots on blades #1 and #2 were found to be open from .007 to .010 inches in the non-blowing condition. These slots were adjusted to provide an average cracking pressure.

Data from run 10 indicated moment spikes in the pitch axis which investigation found to be the pitch link housings on the hub contacting the edge of the crown fuselage. To alleviate the problem metal was removed from the crown fuselage adjacent to the hub. Between tests apparently excessive wobble motion was detected between the rotational section of the hub and stationary collective drum which are joined together by the main hub bearing XW-1-48. The free play of the hub assembly and that of a new spare XW-1-48 bearing were checked and found to be similar. As a result, the hub assembly was considered acceptable to continue testing.

Run Card 14 was conducted with the blade leading edge slots taped closed over the full span (See Figure 3.4.1) and with the blade leading edge root ducts blocked. This was the basic configuration for the balance of the whirl test program. A review of the test data indicated a discrepancy in the relationship of the rotor torque and the rotor thrust. A thrust recalibration determined the discrepancy to be an extrapolation error of the original thrust calibration data which covered only 1/3 of the thrust range.

Additional tests (Run Cards 15, 16, and 17) were conducted after taping the leading edge stops closed to fine trim the rotor for track and balance and to determine available control authority. The track and balance trim was accomplished by closing down the blade root gates on #3 and #4 blades. Control authority was found to be marginal which resulted in deletion of all planned control system tests. Steady control moment and vibratory flap bending is plotted versus vibratory blade pressure in Figure 3.4.2. Blade cuff flap and chord bending bridges were recalibrated prior to Run 16. Balance moments, while not ideal, were judged adequate to begin the performance testing.

The basic hover performance with blade root pressure ratios from 1.0 to 1.7 was accomplished on Run Cards 18, 19, and 20. During run 20, a chirping noise was detected coming from the rotor system. It was assumed that the pitch link housing was again making contact with the crown fuselage so additional metal was removed to provide additional hub/crown clearance. The noise was present on the next start.



Further investigation showed the frequency of the noise to be one per revolution of the rotor. After analysis of the critical rotating components running at this frequency, it was concluded that the noise source was not from any components that could result in catastrophic failure. Accordingly, testing was resumed. Detailed acoustic measurements were made to try and pinpoint the source of the noise.

The effect of lift on the rotor/fuselage interface for the low blowing ratios was completed on Run Card 22 with a normal lift level of 4250 pounds.

The basic hover performance at the higher pressure ratios (1.4 to 2.1) was accomplished on Run Cards 23 thru 30. The effect of lift on the rotor/fuselage interaction test for the high pressure ratio tests (1 4 to 2.1) were completed on Run Card 31 with an applied 7500 pound rotor lift. Additional hover performance data was obtained on Run Card 32 to fill in gaps in data between 0° and 4° θ . After Run 23, the slot deflection proximeter targets were replaced and a recalibration performed.

The effect of zero tip blowing was conducted on Run Card 33 with the blade tip air passages to all four blades blocked.

The effect on blade track of taping the tailing edge slot closed from the blade root outboard to Station 65.25 on Blade #1 only was completed on Run Card 34 (See Figure 3.4.3). The blade root pressure ratios were determined at lift forces of 4,000, 6,000, and 8,000 pounds and blade angles of 0° and 6°.

The effect on blade track of changing the #1 blade angle from 0° to -1° 10 minutes and then -1° 50 minutes was conducted on Run Cards 35 and 36. The pressure ratios were determined at lift forces of 4,000, 6,000, and 8,000 pounds with collective angles of 2° and 8.5° .

The effect on track and balance, of adding four (4) pounds to the tip of #1 blade, was attempted, but due to excessive whirl tower structural vibration ($\pm25,000$ in-lb at 290 RPM) caused by this unbalance, the planned tests on Run Card 37 were terminated.

Additional hover performance was conducted on Run Cards 38 and 39 with blowing ratios of 1.4 and 1.7 and collective angle positions of .75, 1.5, 2.25, 3, 4, 5, 6.25, and 8.0 degrees. These data points were needed to complete the performance envelope. All systems were recalibrated at the conclusion of tests and prior to the start of tear-down. The four blades were removed from the hub and individually checked for air flow rate, slot cracking pressure, and slot deflection.



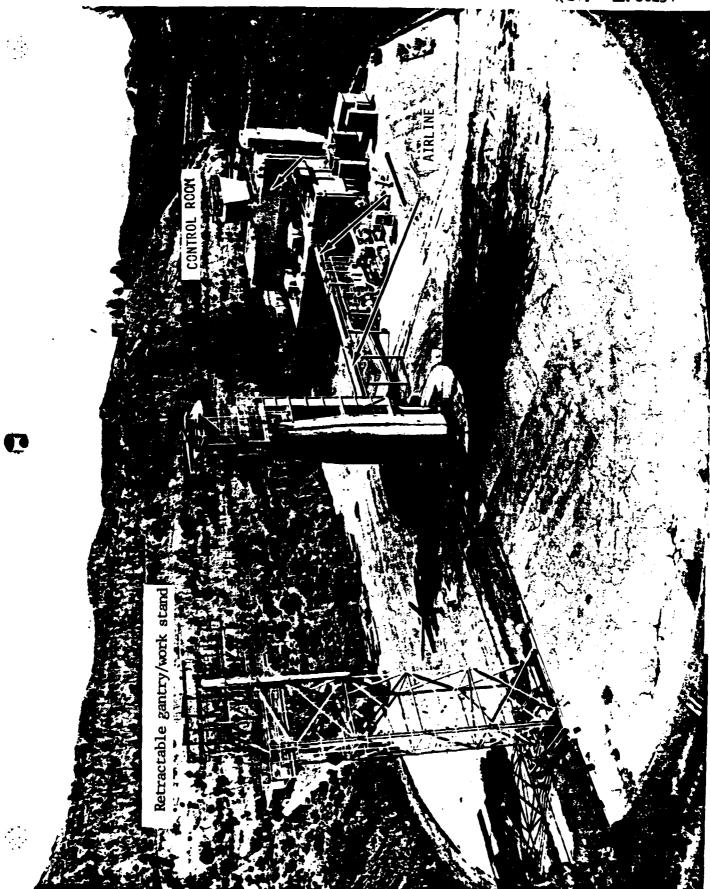
The following blade root gate open areas were measured at the completion of the test program and were effective for Run Cards 18 thru 39:

Blade No.	Serial No.	Area (In ²)
1	1002	11.60
2	1004	8.60
3	1005	5.05
4	1003	7.15

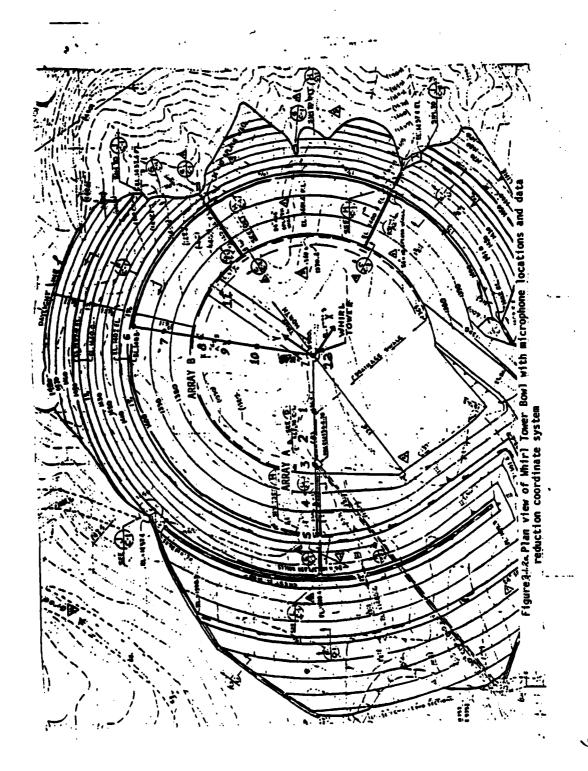
3.5 Derived Parameter Equations

The significant parameters (variables) both measured and calculated and their neumonics are defined in Table 3.5.1. Equations used to calculate non-dimensional and unmeasured parameters are detailed in Table 3.5.2.

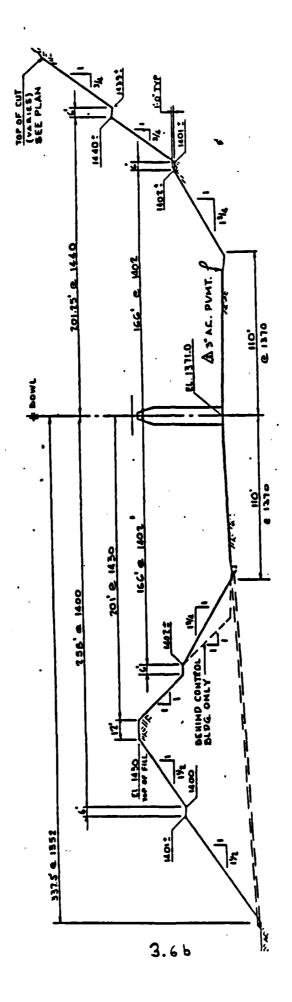
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Figure 3.12 Cross-section drawing of Whirl Tower Bowl

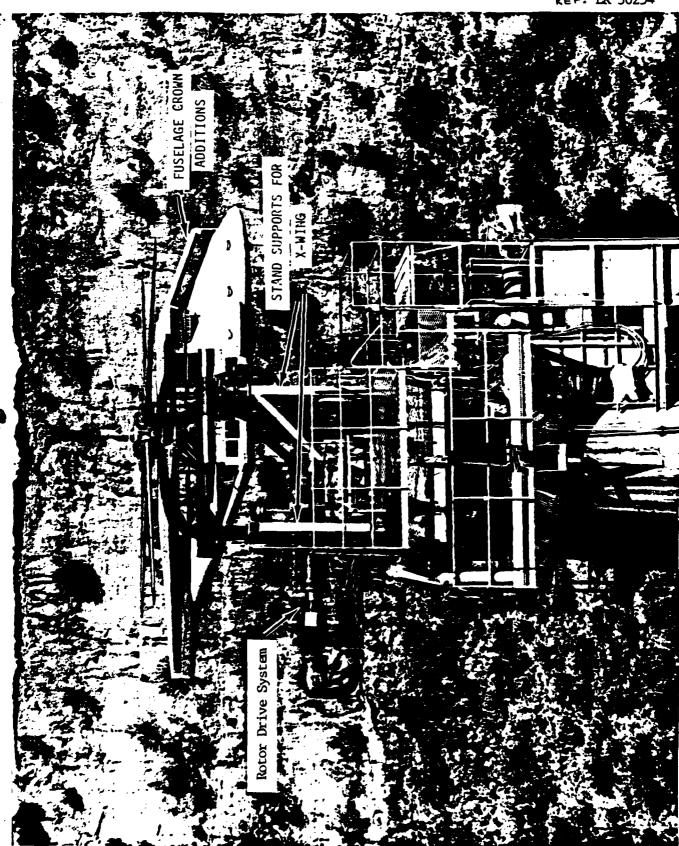


Figure 3.1.4

Module Air Supply System Schematic

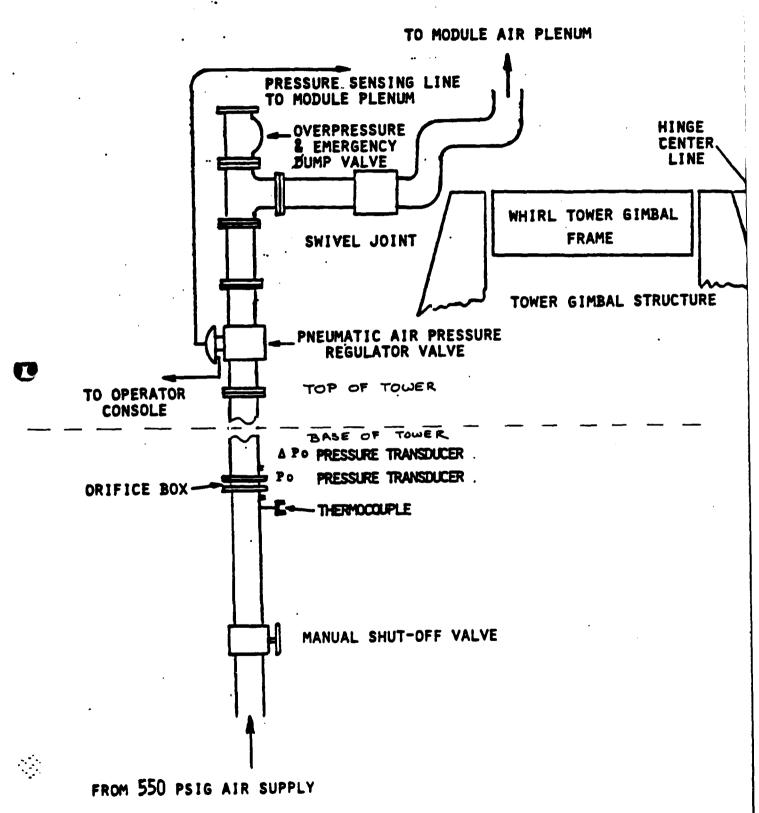
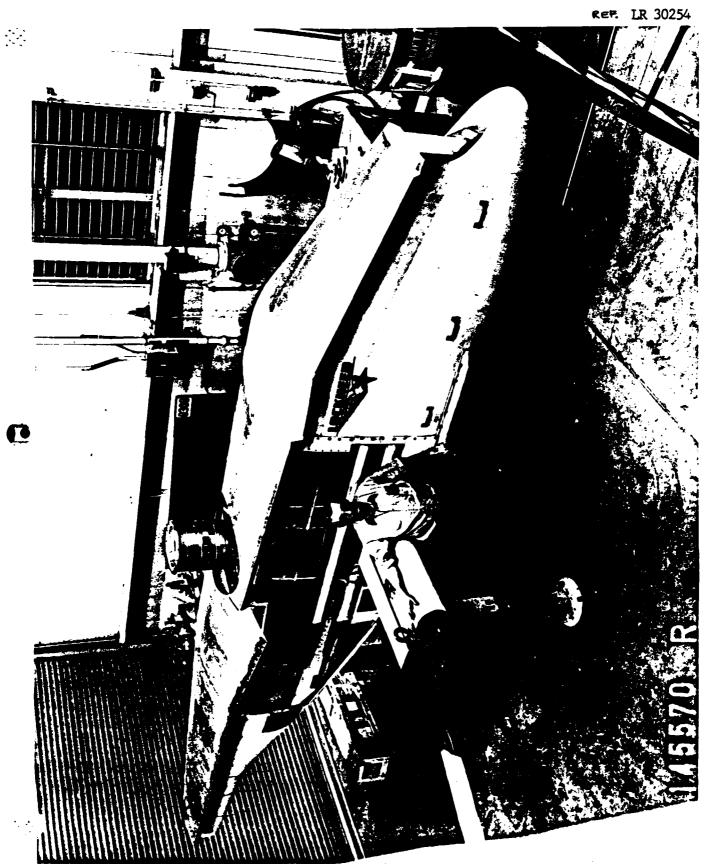
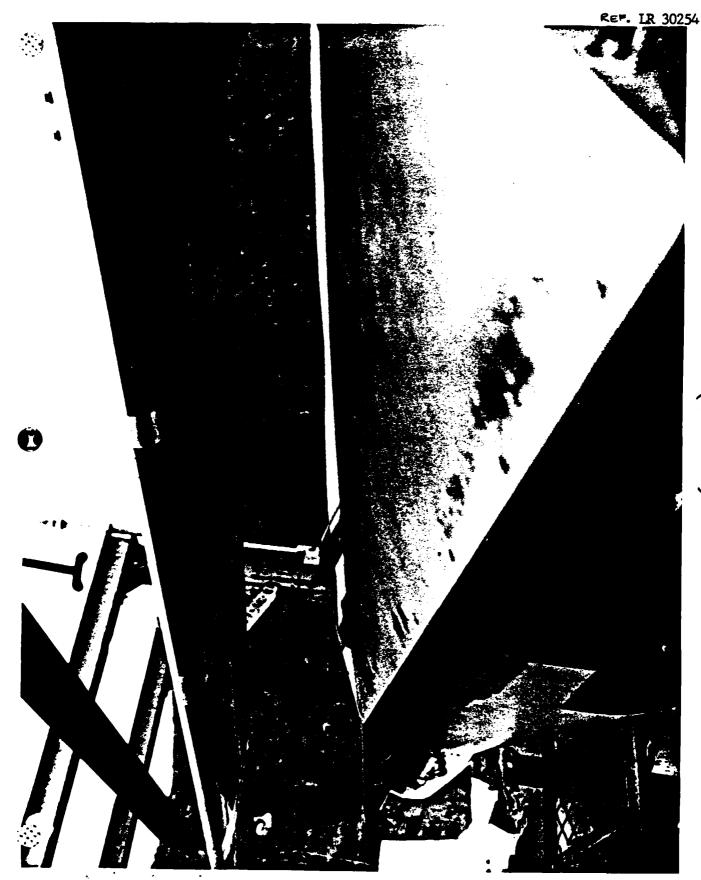


Figure 3.1.5a (PHOTO NO. 4)

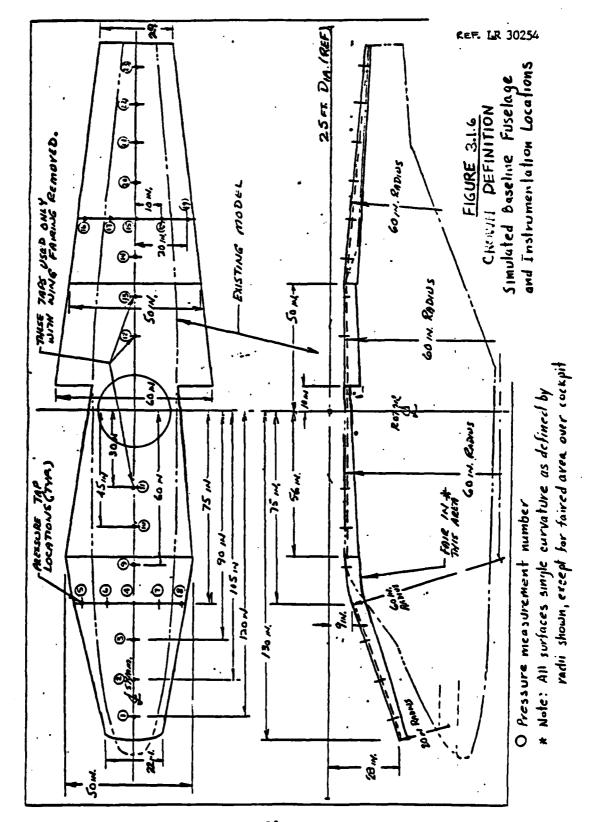


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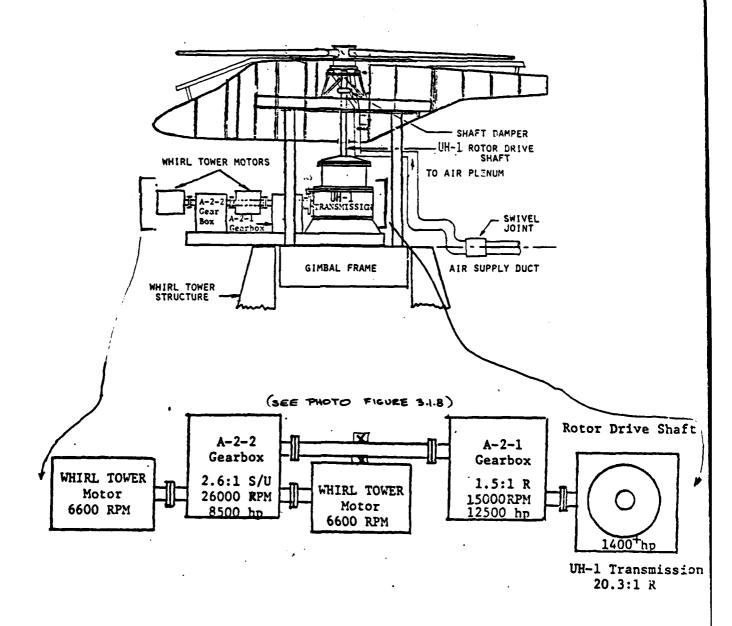


Figure 3.1.7 Drivetrain Schematic

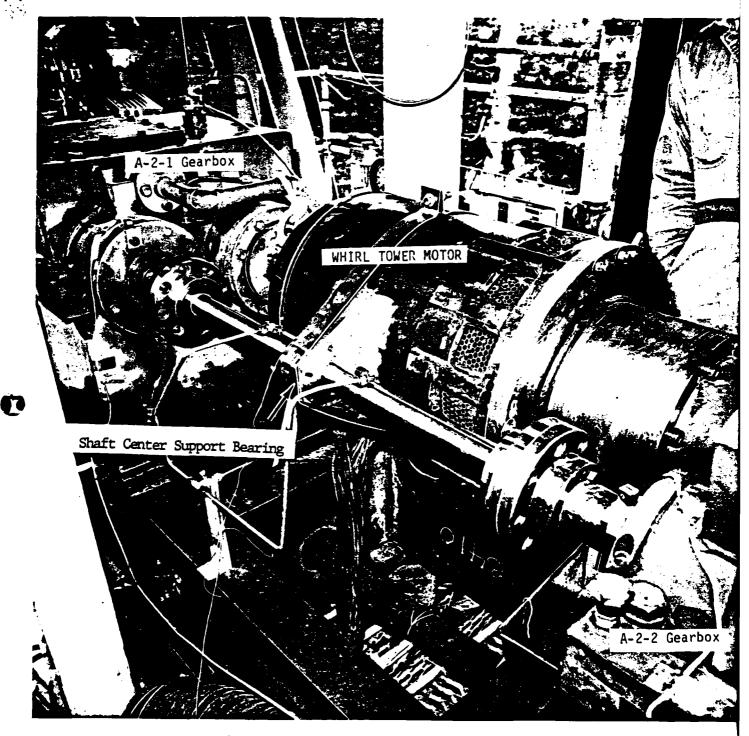
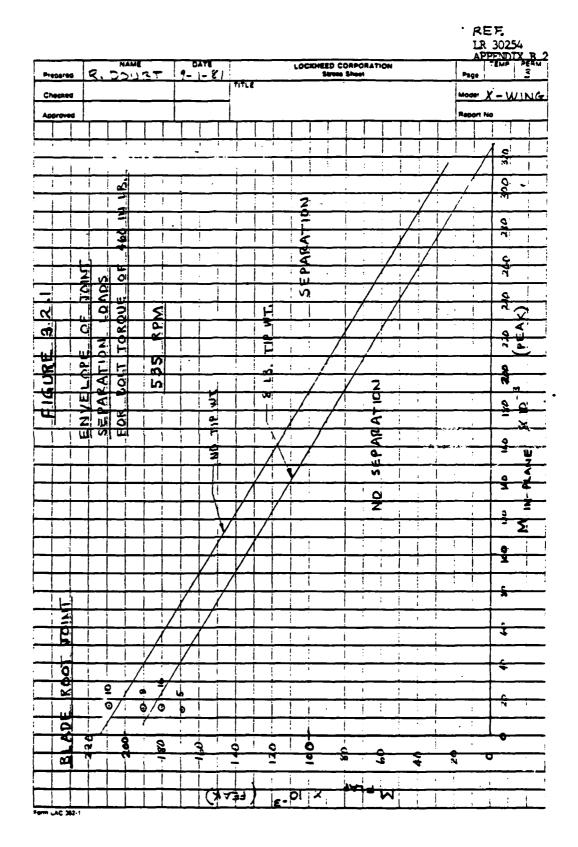


Figure 3.1.8 (PHOTO NO. 6)

ROTOR DRIVE GEARBOX HIGH SPEED COUPLING SHAFT REDESIGN - INSTALLATION FOLLOWING INITIAL SHAFT DESIGN FAILURE



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PE(IR)1T FSI V-20,21 19 59 19 - 30 PSI V-22,23 19 - - 31 77 - - 31 Lill in.lb. - 21 61 21 - 3 Servo Console MH1 in.lb. - 22 62 22 - 3 Servo Console XpC in^/In.lb.** - 39 79 30 - 6 Servo Console Tg in - 20 60 20 - 4 Servo Console Tg in - 39 79 30 - 6 Servo Console Tg in - 20 60 20 - 4 Fig Fig - - - - - - Tg - - - - - - - - Tg	~	Total Preus. TR. Edge 41 Blade	PT(R)17A		V-10,19	E I .	3	91	•	39	
V-22,23 Lill in.lb 21 61 21 - 2 Servo Consolo Hill in.lb 22 62 22 - 3 Servo Consolo X _F C in°/in.lb.** - 39 79 30 - 7 Servo Console X _F C in°/in.lb.** - 39 79 30 - 7 Servo Console X _F C in°/in.lb.** - 39 79 30 - 7 Servo Console T _H lb 20 60 20 - 4 F _T P P _T P FSI - 23 63 23 - 5 Temp. Rodr -CHIS to Di	•		PS(R)IT	151	V-20,21	61	8	5	•	93	
Tr(29) Tr Fest				•	V-22,23			_			
Lill in.lb.	in.	_	PT(29)1T	194	•	37	u	1	ı	31	
M#1 In.lb. - 22 62 23 - 3 Servo Console X _{FC} In²/In.lb.** - 36 78 29 - 6 Servo Console T _H lb. - 39 79 30 - 7 Servo Console T _H lb. - 20 60 20 - 4 P _{TP} F6I - - - - - - - T _P F6I - - - - - - - - T _P F6I -	عب	Rotor Priment, Roll Hub (1)	Ē	In.1b.	i	7	19	2	١.	~	Servo Consola
X _H C In ^a /in.lb.** 38 78 29 6 5ervo Console X _H C In ^a /in.lb.** 20 60 20 1 Sensor T _H lb. 20 60 20 1 P _{TP} P6I 23 63 23 5 T _P O _F - - - - Temp. Rode -Chils to Di - - - - -	2	Notor Moment, Pitch Hub #1 System	ī	tn.1b.	ı	22	3	22		•	Servo Console
X _{FC} in the sensor T _H lb 20 60 20 - 4 Sensor T _H lb 20 60 20 - 4 P _{TP} F6I - 23 63 23 - 5 T _P O _F 7 Temp. Rodr -CHIS to Di		Control, Poll	ر پر	in*/in.1b.**	ı	25	78	8	•	•	Servo Console
Sensor T _H 1b 20 60 20 - 4			ž	in.ib.		£	2	8	•	•	Bervo Console
P _{TP} F61 - 23 63 23 - 5 T _P O _P Teap. Rode -CH15 to Di	•	Fotor Thrust, Mib Sensor	₽ª	.	•	2	8	8	4 .	•	٠
P _{TP} F61 - 23 63 23 - 5 T _p O _f Temp. Redr -CH15 to Di	_		,			1	•	1	t		
Tp Of Chils to Di	~	Plenus Fressure	P. ST.	194	•	8	3	8		'n	
•	—	Henus Tesperature	F.	, ,	•		,	•	•		Temp. Node -CHIS to Dig Ind
				٠	•						• TR 30:
	ح م	ren loop Closed loop center									254

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Table 3.3.1 Cont'd

도리	rtik (i). Description	SMBOL	CNITS	Š	2 E	PAC PAGE	8 8	S S S S S S S S S S S S S S S S S S S	DYN. DATA PRIORITY	768400
			ı							
~	24 Valve Slot 81	V 6−1	ġ	1	•	•	,	,		CBC 12 CN 5
~~	25 Valve Slot 62	VS-2	Ę	1	1	•	1	•		0.
.~	26 Valve Slot 13	V6-3	÷			ı	•	•		•
	27 Valve Slot 84	7-97	÷	•	٠	•	ı	•		₹ 5.
144	28 Valve Slot 85	. S-8V	Ė	•	•	٠	•	•		. • CH 15
~	29 Valve Slot \$6	9 90	ŧ	1	•	i	1	•		8C HO .
~	30 Valve Slot 07	V6-7	į		•	•	ı	•		• Ci 29
,- 1	31 Valve Slot 10	VS-6	£.	•			•	•		
-	32 Crown Press 81	 	192	7	•	•	•	7		
~	33 Crown Press 62	K-2	151	7	•	٠	٠	1-2	•	•
~	34 Crown Press (3	R-3	192	7	•	•	•	1-3		
•	35 Crown Press 64	7	194	1-10	•	•	•	7		
100	36 Croun Press (5	PC-5	156	2-30	•	•	ı	1-5		
~	37 Crown Press 66	8C-6	2	**	•	•	•	*		
	38 Crown Press 87	FC-7	192	6-3	•	•	•	1-1	•	
	39 Crown Press 10	£€	156	7		ŧ	•	1-8		
•	40 Crown Press 19	. 6-28	12	2	•	•	٠	1-9		
•	41 Etatic Press TR Edge #1 Blade (.298)	P _S (29)1T	19	•	7	=	٠	ı	33	
•	42 Total Precs TR Edge #1 Blade (.44R)	P _T (44)]T	192	•	42	2	•	•	8	
•	4) Static Press TR Edge () Blade (.44R)	P _T (44)1T	150	•	₽.	=	1	ŧ	*	
•	44 Total Press TR Edge #1 Blade (.59R)	P _T (59)1T	191	•	\$	2	77	•	ĸ	
•	45 Static Fress TR Edge #1 Blade (.59R)	P _S (59)1T	156	1	\$	2	ŧ	١.	*	
•	46 Thtal Press TR Edge #1 Blade (.74R)	P _T (74)1T	151	•	₩.	2	•	ı	37	
•	47 Static Press TP Edge #1 Blade (.74R)	P _S (74)1T	184	•	Ç	- 6	•	ı	98	
•	48 Total Press TR Edue #1 Blade (.66R)	P _T (86)1T	194	•	7	2	•	•	33	
→	49 Static Press TR Days #1 Blade (.88R)	P _S (86)]T	152	•	\$	2	•		Q	
•	50 Total Press TR Edge #1 Blade (Tip)	P _{T(T)}]T	151		8	3	1	•	\$	
•	Crea loss									

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	Table 3.3.1 Cont'd	Cont'd					:		
ETT GESCHIPTION	SVIEDI	CNTTS	¥	28	3£	35	S K	PRICHTY	West
51 Static Press TR Edge (1 Blade (Tip)	PS(T)17	194		3		•	1	\$	
52 Total Press Lead Edge #1 Blade (.598) P1(59)1L	1) PT(59)1L	12	•	3	z	•		\$	C/O only
53 Total Press TR Edge (2 Blade (.59R)	PT(59)27	121	•	•	٠	•		3	No Good
54 Total Precs feed Edge 62 Blade (.599) Pr(59)24.	R) PT(59)2L	198	1	S	£	•	1	s	C/O only
55 Total Press TR Edge (1 Blade (.59R)	PT(59) 3T	757	•	% .	8	ı		3	
S6 Total Press Lead Edge [] Blade (.59R) PT(59)]L	R) PT(59)3L	181	ì	ı	•	•	•	8	No Good
57 -Total Press TR Edge #4 Blade (.59R)	PT(59)4	152	1	S .	2	•	•	z	
58 Total Press Lead Edge 14 Blade (.59R) Pr(59)4L	R) P_(59)4L	1981	•	*	*	•	•	S	C/O only
59 Total Press Lead Edge (1 Blade (.728) Pr(72)1L	R) P _T (72)1L	181	•	. 23	6	•	ı	*	C/0 only
60 Pitch Link Load		in.1b.	1	2	3	•	1	8	
61 Flat Bending (1 Blade (.25R)	Mf(.25)1	in.1b.	OTA ATO	10	3	2	•	8	
62 Flap Bending #1 Blade (.60R)	Mf (.60)1	1n.1b.	ī	=	33	=	•	*	
63 Flap Brotling (1 Blode (.80R)	Mf(.00)1	In. 1b.	. V12	12	25	22	ŧ		٠
61 Flap Bending #2 Blate (Ouff)	ME(R)2	in.1b.	KIN	13	S	=	ı	\$	
65 Flap Bending (3 Blade (Cuff)	Mf (R) 3	Jn. Jb.	N	=	3	=	•	×	
66 Flap Bending 14 Blade (Ouff)	ME(R)4	in.1b.	\$IA	. 15	22	15	ŧ	\$	
67 Chord Bending #1 Blade (.25R)	Hc(25)1	th.lb.	9 1	91	3	2	ŧ	*	
68 Chord Bending #1 Blade (.40R)	Mc(40)]	fa.tb.	CIV	13	23	11	ı	23	
. 69									
N Crown Press. 810	PC-10	198	BF-10	•	•	L	1-10		
71 Crown Press. #11	IC-11	12	11-11	•	ı	ı	11-11		
72 Crown Press. 612	FC-12	194	BF-12	•	ı	1	1-12		
73 Actor Moment Roll Hub 62 System	LM2	.di.ni	•	ALTERNATE	1	ı	•		Servo
74 Rotor Moment Pitch Bub §2 System	18 13	in.1b.	,	ALTERNIE	•	ı	i		Servo
75									
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 Closed loop center
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Cyclic Mitch, Actuator	,	i i			× ×	3	x		. .3	
2 Actuator Position	, R	į			•	•	:	•	٠,	Console
82 Coll. Trail. Edge Act. Left* 1	j	ij	•		•	1	•	•		Console
Preumatic Coll. Valve Act.	B	ë		•	ı		- 1	•	a	Console
~	3 -	Ė		•	8	3		•	=	•
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			٠							
90 High-Speed Shaft Lat. Accel. +2003 A	MES Y	,	_	ž	•	•	08013			600 Nz
	•		• •							
High-speed Shaft Long Accel. +200s A	AMES X	; -		73	•	•	OEC 13	•		600 Bg
M.b Adapter Lat Vibr. +500°s	Aug Y	;	_	V27	•	•		•		•
Mac Adapter Long. Vibr. +500°s	Ages X		-	87	•	•	OSC 13	ŧ		
-	. EC-23	<u>19</u>	ı	1	•		•	7.		
-	PC-14	194	*	M-14	1	•	•	7		
-	PC-15	191	45	F-15	•	٠,	•	7		
•	RC-16	194	-	P-16	•	ı	•	Į		
	FC-17	. 194	-		1	ı	1	3.		•
•	FC-18	194				•	ŧ	Ţ		
101 Fotor Brake Frems. (No Mon.W/F) F	PRANTE	1	•	1	ť,	•	•	ı		
	IC-19	19	4	7	•	•	•	I		•

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MACO CO. 20 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	i		Table 3.3.1 Cont'd	Cont'd		\$	ş	Ş	8	1			
Coun Frees (34) IC-20 HSI HY-20 2-9 Coun Frees (3) IC-21 HSI HY-21 2-9 Coun Frees (32) IC-22 HSI HY-21 2-9 Coun Frees (32) IC-22 HSI HY-22 2-9 Coun Frees (32) IC-23 HSI HY-21	E 2	- {	SNBOL	CNITS	8	3	E C	3 8	5 5	PATORITY		шана	Ę
Coon Press (2) FC-21 MST MP-21 - - 2-9 Coon Press (2) FC-22 RET MST -	2		1C-28		8-18	٠,	•	•	I				
Coom Press 123 FC-22 FBI MF-22 - <td>ž</td> <td></td> <td>K-21</td> <td>192</td> <td>12-4</td> <td>•</td> <td></td> <td>•</td> <td>ĩ</td> <td></td> <td></td> <td></td> <td></td>	ž		K-21	192	12-4	•		•	ĩ				
Count Press 123 Count Press 123 In.18.	50	Crown Press 122	KC-22	.	12-34	•	•	1	3-10				
Operator Choiced benealing Spicialise H _{CYC Mark 1} /T _{CYC Mark 1} Heat 1.33	3		M _{R(R)} 1	th. lb.	ı	•	•	*	1	=			
Crown Press (23) FC 23 FB 1 NF-23 -<	100	Cyclic Chord Bend	PCY(R)	.a.	•	•	•	2	•	st .			
Crown Press 124 FC 24 NEX NEV-24 - - 2-12 Upper Next Bast ing Tamp. T189 °P -	8		1C 23	194	M -23	•	•	ı	11-2				
Hyper Nust Bacting Tamp. 1988 97	200	Crow Press 124	22		16 -24	٠	i,	•	2-13				
Hyper North Bearing Temp. 119 97	110	•	••			•							
Hoper Bearing Tump. 1110 9° - - - - - -	111		198	8	•	•	•	•	ì			Bode. 83	=
Librer Flate Liube Old Out Yamp. 1504 97	112	Input Bearing Two	TIE	&	ı	•	٠	•	•		•		2
Upper Suctions Valve Assay, Tamp. 1954A. 97	113		2	د	•	•	•	•	,		•		2
Upper Suctace Valve Assy, Yeap. 1954a-3 Pp	114	Upper Surface Val	W.GL		ı	•	•	•	•		•		3
Libe Oil in at Rump Outliet Yamp. Titol Op	115		18W-2	٠.	ı	•	٠	•	1	•	į	Podr.	2
Lube Oil in at hump Outlat Yang. Titol "P"	716	Upper Surface Val	18W-3	å	1	•	•	•	•		•		•
Floaring Temp. Floaring Temp. Gear Box Lube Oil Out Temp. Gear Box Lube Oil Out Temp. Floater Bi States Winding Temp. Floater B	111				•								
Gear box Libr Oil Out Twap. TGBLA OP	=	Lube Oil in at Rump Outlet Yeng.	101			ı	•	ı	•	•	•		2
Gear Now Lube Cell Cust Tamp. 1936-1 OP	119		TORET		ı	•	٠,	•			•		=
Notice (1) States Winding Tump. 200-1 °p	22	Gear Nos Lube Oil	1001	<u>چ</u>	1.	•	•	•			•		2
Notoc 82 Statoc Winding Tump. 2002-2 Op	121		7-92	<u>چ</u>	٠,	ŧ	•	•	•		•	•	2
Notoc 62 Statoc Winding Tump. 206-2 Op	122	•	٠		•								
Notice 62 Notice Winding Swep. Swe-2 Op	22	Notor 62 Stator Winding Tump.	2-9ac	<u>چ</u>	ı	•	•	٠	ı		•	-	=
Neak Total Frees.IR hige 61 (.50m) Pyre(59)ly M61	124		7-8-7	<u>.</u>	•	•	٠	•			•	-	22
Post Total Press.IR Rige 01 (.308) Pyt(59)1T MEI	23				•								
	2	Nest Total Press.TR EDge (1 (.500)	PTP(59)1T	1	•	1	•	ı	•	•	Peaker		
R.	133												
	128												

* Open loop ** Closed loop cent Dide_rook;13

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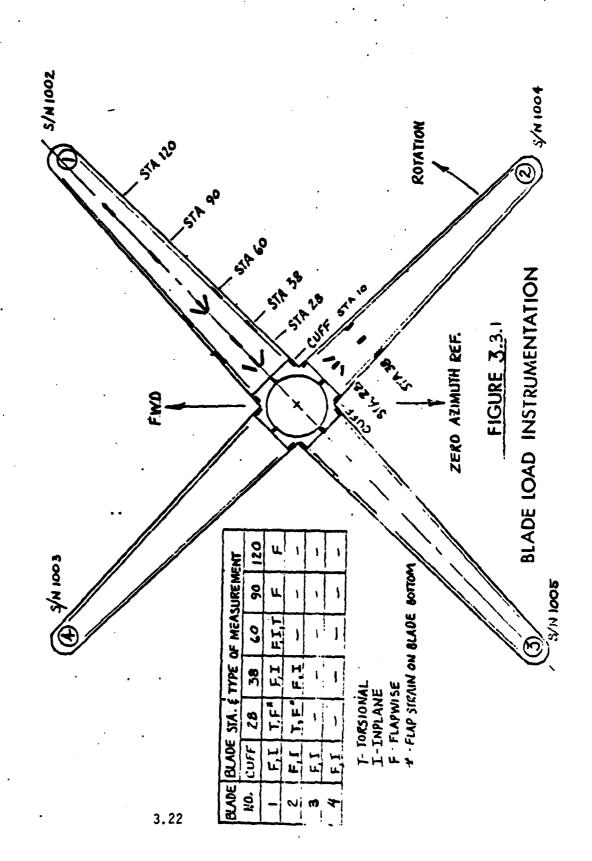
ţ		lable 5	lable 3.3.1 contra		3	3		34	DOM. LATE	
2	DESCRIPTION	SYNEXX	UNITE	Ž	\$	MZ	5	5	PRICEITY	CONTRAINS
		٠								
2										
2										
2			· ·	•						
22	132 Totaion [1 Blade (.188)	Ac(10)1	ta.lb.	3	•	3	•	•	22	
133	Flap Stress \$1 Blade (.10)1		1	4-1	٠,	•	æ	•	•	
3	Slot Defl. #1 Blade TR Edge (.29R)	h(29)1T		•	2	2	٠	1	57	
161	Slot Defl. 61 Blade TR Edge (.448)	h(44)1T	ġ	•	#	2	#	ı	3	
162	Slot Defl. (1) Blade TR Edge (.598)	h(59)1T	÷	ı	2	2	2	•	*	
163	Slot Lefl. 41 Blade TR Edge (.748)	h(74)1T			8	E	•	•	S	
3	Slot Defl. #1 Blade TR Edge (. 88R)	h(88)1T	ë.	ı	*	Z	2	•	3	
165	Model Flow Orifice P H	Ē	191	•	22	, K	ı			
991	166 Hodel Flow Orifice Upstream 0-600 MSI POU	11 100	. 194	4-32	*	×	٠	•		
167	Nodel Flow Orifice Temp	٤	٠	ı	•	1	•	1	670	Dig Temp Lnd
168	168 HoD. Flow Orif. P Low Nange +1PSI	ğ	. 12	•	\$	8	•	1		
302	•									
20		•	•		•		۵.			٠
304						•				٠
332	Torsion (2 Blade (.188)	Mc(18)3	in.1b.	ť.	1	•	•			
333	Flap Stress #2 Blade (.188)		ë ë		•	•	•			
797	Flap Bending (2 Blade (.258)	M(25)3	H in. in.	•	•	•	•			
367	Chord Bending §2 Blade (.258)	Hc(25)3	# 5.	•	٠	•	4	•		•

* Open loop ** Closed loop cent DARA AME. 13

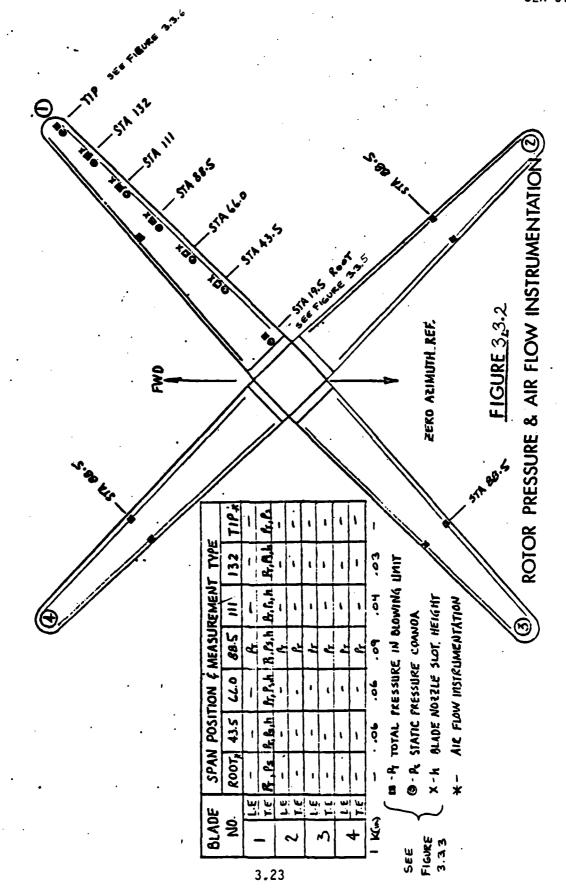


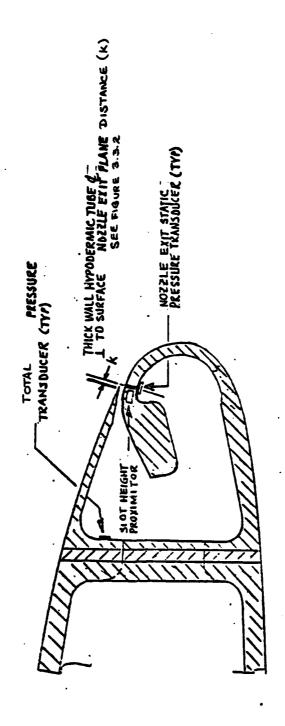
Table 3.3.2 Manual Measurements

- o Rotor RPM
- o Rotor thrust (lift)
- o Pitch moment
- o Roll moment
- o Berometric pressure
- Ambient air temperature
- o Collective blade angle
- o Plenum pressure
- o Wind velocity
- o Wind direction
- o Rotor shaft torque
- o Orifice box air temperature



•••





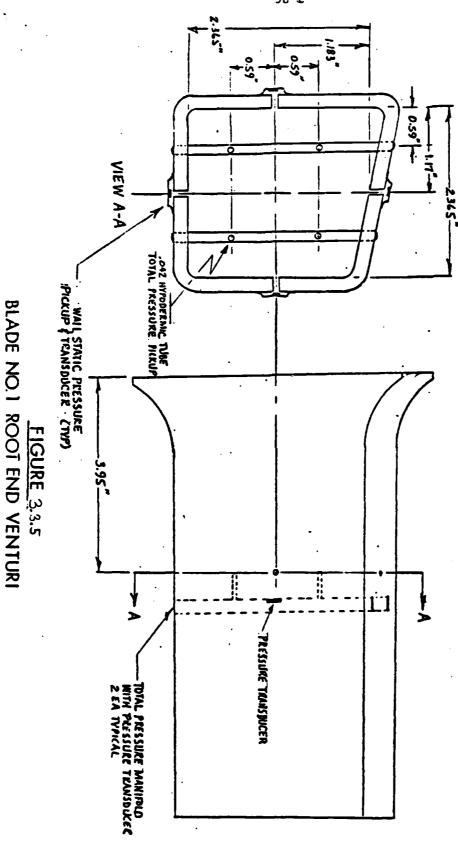
NO. 1 ROTOR BLADE INSTRUMENTATION (T.E.)

FIGURE 3.3.3

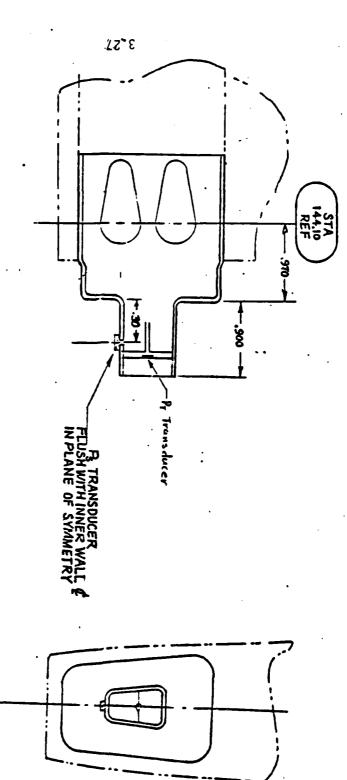


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S/N 1002 ROTOR BLADE TRAILING EDGE SHOWING PROXIMETER TARGET AND EXPOSED NOZZLE LIP STATIC PRESSURE PICKUP HOLE



AIR FLOW INSTRUMENTATION



BLADE TIP SLOT AIR FLOW INSTRUMENTATION

FIGURE 3.3.6

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CHRONOLOGICAL ORDER OF MITHL TESTS AND SYSTEM CALIBRATION X-WING

3 6	REF. LR 30254
DATA CEVIRAL TEST NO.	17238 17248 17254 17253 17323 17323 17404 17414 17445 17446 17446 17446 17446 17446 17446 17446 17446 17466 17466 1766 17
DESCRIPTION OF TEST	S/N 1003 Blade Air Flow Calibration (Green corks) S/N 1003 Blade Air Flow Calibration (Tip plugged) S/N 1004 Blade Air Flow Calibration S/N 1005 Blade Air Flow Calibration S/N 1002 Blade Air Flow Calibration S/N 1005 Blade Air Flow Calibration S/
RUN CARD OR LOG SHEET NO. 2	10717-3
DATE	11-02-81 11-03-81 11-03-81 11-04-81 11-16-81 11-17-81 11-17-81 11-25-81 12-02-81 12-03-81 12-03-81 12-08-81 12-08-81 12-08-81 12-08-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81 12-09-81

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CHKNOLOGICAL ORDER OF WHIRL TESTS AND SYSTEM CALIBRATION X-WING (Cont'd.)

Table 3.4.1 Cont'd

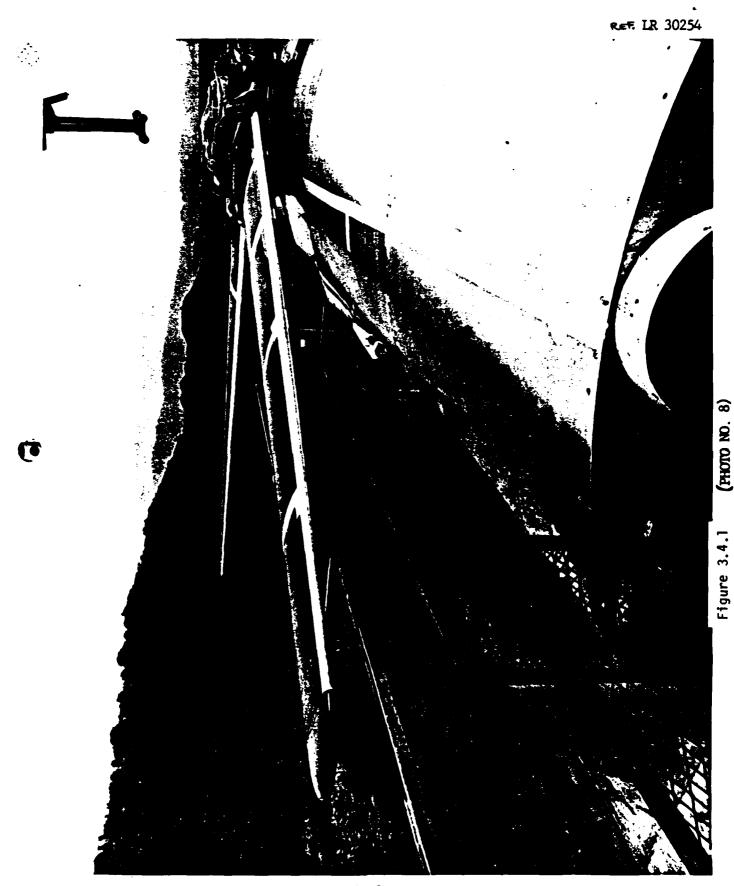
1-07-82		S/N 1002 Blade Air Flow Calibration (Tips open) S/N 1002 Blade Air Flow Calibration	17680
1-08-82		1002 Blade Air	11771
1-12-82		S/N 1002 Blade Air Flow Calibration	17716
1-12-82		S/N 1002 Blade Strain Gage Calibration	17719
1-15-82	10717-5	Hub Plenum Leakage Calibration	17728
1-15-82	10717-6	Plenum Leakage Calibration	17734
1-19-82	10717-7/8	Rotor Shaft-Torque Calibration	17768
1-19-82	9-71701	Potor System-Moment Calibration	17778
1-19-82	10717-10-12	Potor System-Moment Calibration	17785
1-20-82		Rotor Shaft-Torque Calibration	17600
1-29-82	10717-14	Notor Shaft-Torque Calibration	17909
2-01-82	10717-15	Preliminary System Check-out	17939
2-04-82		Potor Shaft-New Gages-Torque Calibration	16027
2-05-82	Run Card 1	Track & Balance	18052
2-08-82	Run Card 2	High Speed Shaft Vibration	16059
2-00-8	Run Card 3	High Speed Shaft Vibration	16067
2-09-82	Pun Card 4	High Speed Shaft Vibration	18113
2-11-85,	Run Card 4	Track & Balance	18127
2-12-82	Run Card 5	Track & Balance	18143
2-15-82	Run Card 6	Track & Balance	18147
2-16-82	Card		18152
2-19-82	Run Card 8	Track & Balance	18238
2-19-82	Run Card 9	Track & Balance	18249
2-22-82	Run Card 9	Track & Balance	18264
2-24-82	Run Card 10	Track & Balance	18288
2-24-82		Rotor System Moment Calibration	18301
2-24-82	Run Cards 11/12	Track & Balance-Start Task A-1	18306
2-25-82	Run Card 13	Task A-1	18312
2-25-82	Run Card 14	Task A-1	18343
2-25-82		Task A-1	18346
3-03-82	10717-25	Lift & Moment Calibration	18365
3-04-82		Lift & Compension/Moments	18378
3-05-82	10717-29	Plenum Lift & Moment/Slot Deflection	18383
3-08-82		Track & Balance-Control Sys. CO	18400
3-08-82	10717-32	Blade Cuff Calibration	18402
3-09-82	Sard	Track & Balance	18408
3-09-82	Run Card 17	Track & Balance	18411

REF. · LR 30254

Table 3.4.1 Cont'd CHRONOLOGICAL ORDER OF WHIRL TESTS AND SYSTEM CALIBRATION X-WING (CONE'd.)

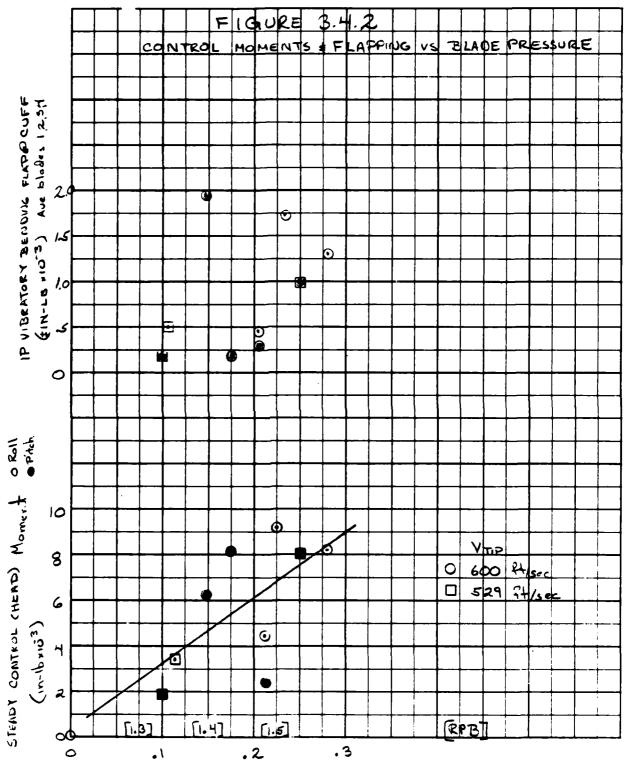
16431 18449 18453 18460 18463	18514 18527 18537 18530 18579 (Woid) 18587	16599 16613 16633 18637 18643 18646	18652 (Void) 18657 18662 NA 18671 18673 18673	18718 18738 18740 18750 18757 18766
Basic Hover Performance Part I Effect of Lift on Rotor/Puselage Basic Hover Performance Part I	Basic Hover Performance Part II	Basic Hover Performance Part II Effects of Lift on Rotor/Fuselage Part II Effects of Lift on Rotor/Fuselage Part II Basic Hover at Press Ratio (1.0-2.1) FSI Basic Hover-No Tip Blowing Trailing Edge Taped-Root To Sta. 65.25 No. 1 Blade/Blade Angle - 10 10	No. 1 Blade/Blade Angle - 1 50' Tip Weight Added No. 1 Blade 4# Basic Hover-Collective Sweep Orifice AP Transducer-Calibration Basic Hover-Collective Sweep Plenum Pressure Transducer Calibration Rotor Shaft Torque/Plenum Leakage	S/N 1002 Blade Air Flow Calibration S/N 1004 Blade Air Flow Calibration S/N 1002 Blade Air Flow Calibration S/N 1003 Blade Air Flow Calibration S/N 1005 Blade Air Flow Calibration S/N 1004 Blade Air Flow Calibration S/N 1005 Blade Air Flow Calibration
Run Card 18 Run Card 19 Run Card 20 Run Card 21 Run Card 23	Card Card Card Card Card		Run Card 36 Run Card 37 Run Card 38 10717–40 Run Card 39 10717–39 10717–39	
3-10-82 3-12-82 3-12-82 3-15-82 3-18-82	3-19-82 3-19-82 3-22-82 3-22-82 3-25-82 3-25-82	3-26-82 3-29-82 3-30-82 3-31-82 3-31-82	3-31-82 4-01-82 4-01-82 4-02-82 4-02-82 4-02-82 4-05-82	4-08-82 4-12-82 4-13-82 4-13-82 4-13-82 4-15-82

ROTOR SETUP ON THE WHIRL TOWER SHOWING BLADE LEADING EDGE SLOTS TAPED CLOSED (PHOTO NO. 8)



3.31a

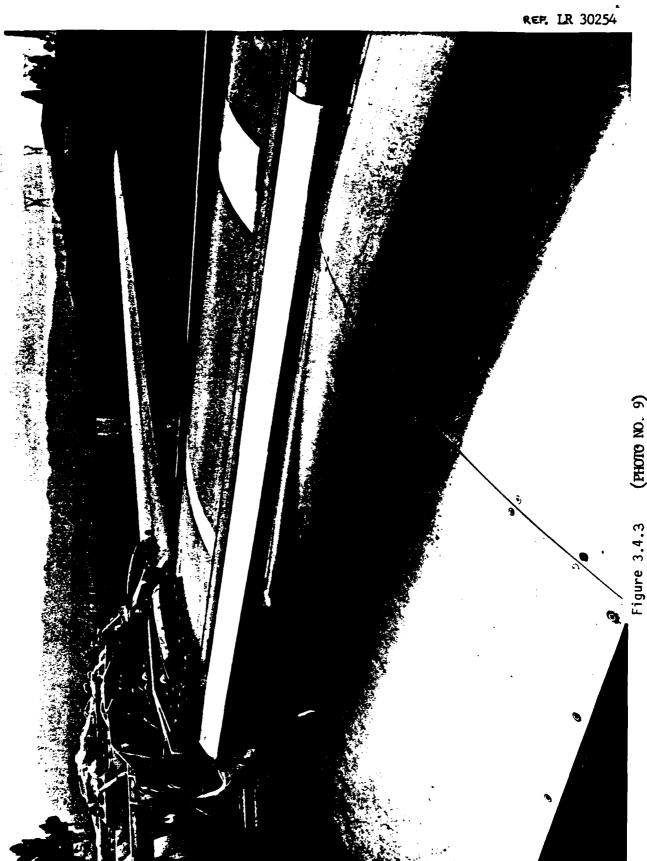




IP VIBRATORY PRESSURE (2.59R (+ prig))
(aue. blodes 1.3.4)

3.31 b

S/N 1002 BLADE TRACKING TEST CONFIGURATION - BLADE TRAILING EDGE STOR TABEL CLOSED OFFICE TREGADED STAN



3.32

TABLE 3.5.1 DEFINITIONS OF VARIABLES FOR X-WING ROTOR TEST AT RYE CANYON

DAT	ΓA	INPIIT	CONSTANTS	

NAME

A2B 2P COSINE COMPONENT VALVE AREA FRACTION

COLL ROTOR/WING COLLECTIVE BLADE ANGLE DEGREES

PATM ATMOSPHERIC PRESSURE LBS/IN2

TEMPO ORIFICEAIR TEMPERATURE °F

TEMPA ATMOSPHERIC TEMPERATURE "F

VMPH VELOCITY OF WIND MILES/HOUR

RPM REVOLUTION/MIN

DATA CONSTANTS SET IN PROGRAM

G GRAVITATIONAL CONSTANT 32.137 FT/SEC2

PI PI

3.14159

ROTOR RADIUS

12.5 FT

FIXED WING REFERENCE AREA 70.7 FT2

SIGMA ROTOR SOLIDITY RATIO

DATA FROM STEADY STATE VALUE FROM HARMONIC ANALYSIS

LHM ROLL MOMENT, HUB LOAD CELLS FT-LBS

MHM PITCH MOMENT, HUB LOAD CELLS FT-LAS

PTP PLENUM TOTAL PRESSURE LBS/IN2

T ROTRO/WING THRUST HUB LOAD CELLS LBS

TORQ ROTOR TORQUE, MEASURED FROM SHAFT TORQUE FT-LBS

DATA CHANNEL MAXIMUM VALUE, CORRECTED WITH ZERO RUN

PT59T PEAK TOTAL TRAILING EDGE, SLOT PRESSURE LBS/IN2

BLADE STATION .59

H59T TRAILING EDGE SLOT DISPLACEMENT, STATION .59R LBS/IN2

Reference APPENDIX R.2.2 LR 30254

TABLE 35.1 Cont's DEFINITIONS OF VARIABLES FOR X-MING ROTOR TEST AT RYE CANYON

DATA CHANNEL AVERAGED, CORRECTED WITH ZERO RUN ORIFIC DELTA RPESSURE

POH ORIFIC DELTA PRESSURE HIGH

PDL ORIFIC DELTA PRESSURE LOW

PTO ORIFIC TOTAL PRESSURE LBS / IN2

PTRT #1 BLADE PEAK TOTAL ROOT PRESSURE TRAILING BLADE

PSTAT STATIC PRESSURE (ROOT BLADE REF) L65/IN2

TEMPP PLENUM TEMPERATURE 'F

XP PNEUMATIC CYCLIC PITCH ACTUATOR DISPLACEMENT INCHES

XR PNEUMATIC CYCLIC ROLL ACTUATOR DISPLACEMENT INCHES

DATA VALUES FROM CALIBRATION CONSTANTS

A1B 1P COSINE COMPONENT VALUE AREA FRACTION

BIB 1P SINE COMPONENT VALUE AREA FRACTION

RHO MASS DENSITY OF AIR SLUGS / FT3

WPB MEASURED AIRFLOW OF BLADE NUMBER 1 LBS /SEC

WPL PLENUM AIRFLOW LOSS LBS / SEC

DATA VALUES CALCULATED FROM CONSTANTS AND INPUTS

DEL RELATIVE ABSOLUTE PRESSURE

MPS ROTOR SHAFT HORSE POWER

OMEGA ROTOR ROTATIONAL RATE RAD/SEC

SIGMAD RELATIVE ABSOLUTE DENSITY

THETA RELATIVE ABSOLUTE TEMPERATURE

DATA VALUES DERIVED FROM FUNCTIONS

LH ROLL MOMENT, HUB LOAD CELLS FT-LBS

MH PITCH MOMENT, HUB LOAD CELLS FT-LBS

WO MEASURED AIRFLOW LBS / SEC

Reference APPENDIX R.2.2 LR 30254

TABLE 3.51 Codd DEFINITIONS OF VARIABLES FOR X-HING ROTOR TEST AT RYE CANYON

DATA VALUES DERIVED FROM ALL SOURCES

CMRS	NON-DIMENSIONAL PITCH MOMENT COEFFICIENT, ROTARY WING, HUB LOAD CELLS
CLRS	NON-DIMENSIONAL ROLL MOMENT COEFFICIENT, ROTARY WING, HUB LOAD CELLS
CPS\$	NON-DIMENSIONAL ROTOR SHAFT POWER COEIFFICIENT, ROTARY WING
VJR	ROTOR (BLADE ROOT REF) EQUIVALENT AIRFLOW JET VELOCITY FT/3EC
TSL	ROTOR/WING THRUST, HUB LOAD CELLS, SEA LEVEL DENSITY REFERENCE LOS
DLSL	ROTOR DISK LOADING LES /FT2
WP	PLENUM AIRFLOW LAS / JEC
WPSL	PLENUM AIRFLOW, CORRECTED FOR TEMPERATURE AND PRESSURE L&S/SEC
НРР	ROTOR/WING PNEUMATIC HORSEPOWER
CMUB	NON-DIMENSIONAL BLADE BLOWING MOMENTUM COEIFFICIENT
QΤ	DYNAMIC PRESSURE AT THE BLADE TIP LOS /FT2
CPPR\$	NON-DIMENSIONAL ROTOR PHEUMATIC POWER COEFFICIENT, ROTARY WING
CMUR\$	NON-DIMENSIONAL ROTOR BLOWING MOMENTUM COEFFICIENT, ROTARY WING
CMR	NON-DIMENSIONAL LADE BLOWING MOMENTUM COEFFICIENT
CPR\$	NON-DIMENSIONAL TOTAL ROTOR POWER COEFFICIENT, ROTARY WING
FMS	SHAFT FIGURE OF MERIT
PMT	TOTAL FIGURE OF MERIT
CPO\$	NON-DIMENSIONAL PROFILE POWER ROTARY WING

Reference APPENDIX R.2.2 LR 30254

DEFINITIONS OF VARIABLES FOR X-WING ROTOR TEST AT RYE CANYON

DATA VALUES DERIVED FROM ALL SOURCES

VJRP	JET VELOCITY (PLENUM REF) FT / SEC
НРС	COMPRESSOR HORSEPOWER HP
CPCR\$	NON-DIMENSIONAL COMPRESSOR HORSEPOWER, ROTARY WING
MJSL	SEA LEVEL REF ROTOR AIR JET MACH NUMBER (BLADE REF)
TORQSL	SEA LEVEL REF ROTOR TORQUE FT- LBS
TEMPPSC	SEA LEVEL REF PLENUM TEMPERATURE *F
PTPSL	SEA LEVEL REF PLENUM TOTAL PRESSURE LOS/IN2
PTRTSL	SEA LEVEL REF #1 BLADE ROOT TOTAL PRESSURE LOS /IN2
RPO	PLENUM PRESSURE RATIO
RPB	BLADE #1 PEAK TOTAL PRESSURE RATIO
HPCSL	SEA LEVEL REF COMPRESSOR HORSEPOWER
HPSSL	SEA LEVEL REF SHAFT HORSEPOWER
HPPSL	SEA LEVEL REF PNEUMATIC HORSEPOWER
HPTRSL	SEA LEVEL REF TOTAL ROTOR/WIND HORSEPOWER
VJRSL _.	SEA LEVEL REF JET VELOCITY (BLADE ROOT REF) FT/SEC
VJSLVT	SEA LEVEL REF ROTOR BLADE AIRFLOW JET VELOCITY ADVANCED RATIO
MTSL	SEA LEVEL REF ROTOR TIP MACH NUMBER
CBLCR\$	BLOWING COEFFICIENT CORRECTED FOR LOCAL VELOCITY EFFECTS
VT	ROTOR TIP SPEED FT / SEC
MT	ROTOR BLADE TIP MACH NUMBER
MHSL	PITCH MOMENT, HUB LOAD CELLS, SEA LEVEL FT-LBS.
LHSL	ROLL MOMENT HUB LOAD CELLS, DENSITY FT-LBS
CT\$	NON-DIMENSIONAL THRUST COEFFICIENT, HUB LOAD CELL, ROTARY WING

Reference APPENDIX K.2.1

TABLE 3.5.2 .. LIST OF EQUATIONS

LR 30254

```
ATB
                     4.82857 * 1.12 * XP
B18
                     4.82857 * 1.12 * XR
                     ([PFRI-PSTAT)/(TEMPP+460.) = 1867.8] - 13.86)/60.
WPB
MPL
                     (2.61 * PTP+1.5)/60.
                     0.0838999*PATM/(TEMPA+460.)
RHO
OMEGA
                     RPM*P1/30.
HPS
                     (TORQ*OMEGA)/(550.*12.)
                     (TEMPA+460.)/519.
THETA
SIGMAD
                     RHO/.002378
DEL
                    PATM/14.7
HO
                    USED AIRFLOW SUBROUTINE FOR CALCULATION
                    T*1000.-(45G.*PTP)
T(corr)
                    MHM - (-136*PTP)
Ш
                    LHM - (-114*PTP)
                    OMEGA * R
VT
                    OMEGAR/49. 1= TEMPA + 460)
MISL
                    MH/SIGMAD
LHSL
                    LH/SIGMAD
                    T/(RHO+S+OMEGAR2)
CTS
CT
                    CTS . SIGMA
                    MH/(RHO * S * OMEGAR 2 *R*12)
ORS
                    LH/(RHO * S * OMEGAR 2 *R*12)
CLRS
                    (550. *HPS)/(RHO * S * OMEGAR3)
CPSS
CPS
                    CPS$ * SIGMA
·VJR
```

T/SIGNAD

TSL.

Peference APPENDIX K.2.1 LR 30254

TABLE 3.5.2 Contil

LIST OF EQUATIONS

HPSSL

TSL/(PI*R·) DLSL WO-WPL WP+ THETA/DEL WPSL $WP = VJR^2/(2*550*G)$ HPP WPB * VJR/(32.174*RHO*PI*OMEGAR²*R²) CHUB QT .5 * RHO *VT2 CPPR\$ 550 *HPP/(RHO * S * OMEGAR3) CHURS WP+VJR/(32.174 * RHO * S * OMEGAR2) CMUR WP * VJR/(32.174 * RHO * PI * OMEGAR 2+R2) **CPRS** CPPRS + CPSS **CPR** CPRS * SIGMA .707*CT 1.5/CPS FMS .707*CT 1.5/CPR **FMT** CPRS - CT2+2+OMEGAR CPOS 7.*1715.*(TEMPP+460.)*(1-PATM PATM+PTP) 2/7 .5 **VJRP** WP*VJRP2/ (2*550*G) HPC (550*HPC)/(RHO*S*OMEGAR3) **CPCRS** (PTRT-PATM) 2/7 - 1 MJSL TORQSL TORQ/SIGMAD TEMPPSL TEMPP*THETA PTPSL PTP/SIGMHD PTRTSL PTRT/SIGMAD RP0 (PTPSL+14.7)/14.7 (PTRTSL+14.7)/14.7 HPCSL HPC*THETA* THETA DEL

HPS/SIGNAD

SER-510072

Reference APPENDIX K.2.1

TABLE 3.5.2 Contil

LR 30254

LIST OF EQUATIONS

HPPSL HPP*THETA* THETA/DEL

HPTRSL HPPSL+HPSSL

VJRSL VJR*√THETA

VJSLVT VJRSL/OMEGAR

MTSL MT/ THETA

CBLCRS CMUR/SIGMA* (1-((1+5.54*CT\$) +VT)/VJRSL)



4.0 RESULTS

Tabulated data is available in Reference 2.2.4.

4.1 Performance Correlation

The plotted data are arranged by increasing tip speed as follows, and are plotted for various blade angles:

Figure No.

Section	Tip Speed	Plot Number	Variables Plotted
4.1	A,B,C, or D*	1	Total Figure of Merit vs. Thrust Coefficient/Solidity
		2	Shaft Figure of Merit vs. Thrust Coefficient/Solidity
		3	Thrust Coefficient/Solidity vs. Rotor Momentum Coefficient/Solidity
		4	Thrust Coefficient/Solidity vs. Total Power Coefficient/Solidity
		5	Thrust Coefficient/Solidity vs. Shaft Power Coefficient/Solidity
		6	Thrust Coefficient/Solidity vs. Compressor Power Coefficient/Solidity
		7	Shaft Horsepower vs. Thrust
		8	Compressor Horsepower vs. Thrust
		9	Total Horsepower vs. Thrust
		10	Shaft Torque vs. Thrust
		11	Rotor Momentum Coefficient/Solidity vs. Blade Pressure Ratio

^{*}A-529 ft/sec; B-550 ft/sec; C-600 ft/sec; D-650 ft/sec



12	Weight Flow vs. Blade Pressure Ratio
13	Thrust vs. Blade Pressure Ratio
14	Total Horsepower vs. Blade Pressure Ratio
15	Blade Pressure Ratio vs. Plenum

The following data are plotted for two blade pressure ratios:

Figure No.

Section	Tip Speed	Plot Number	Variables Plotted
4.1	A,B,C,D	16	Total Figure of Merit vs. Thrust Coefficient/Solidity
		17	Shaft Figure of Merit vs. Thrust Coefficient/Solidity
		18	Shaft Horsepower vs. Blade Angle
		19	Total Horsepower vs. Blade Angle
		20	Thrust vs. Blade Angle

Included on these plots are predictions based on the Cruise 4 and CCHAP programs, Reference 2.3.1 and 2.3.2 respectively.



Comparison with 1979 Test Data

The 1979 test data was obtained from Reference 2.2.1 report. The only tip speed common to both data sets is 529 ft/sec.

- (a) The thrust/power relationship repeats well as shown in Figures 4.1.4A and 4.1.5A.
- (b) The thrust/momentum relationship (see Figure 4.1.3A) is slightly different. The 1979 data indicate for the same momentum coefficient and zero blade angle the rotor produced only 85% of the thrust of the 1982 data. A similar difference seems exists for the higher blade angle data however the 1979 data is for 3.0 degrees which should be lower than the 3.9 degree 1982 data. The reason for the difference at zero is unknown but may be a problem in the thrust measurement correction for plenum pressure.

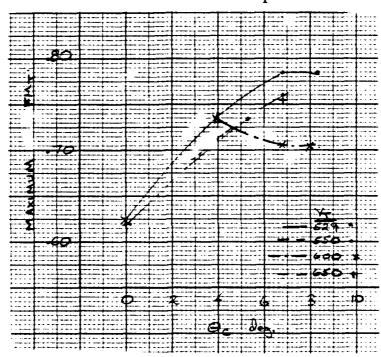


General Comments

Figure No. Parameters

4.1.1 FM_T vs. $\frac{CT}{\sigma}$

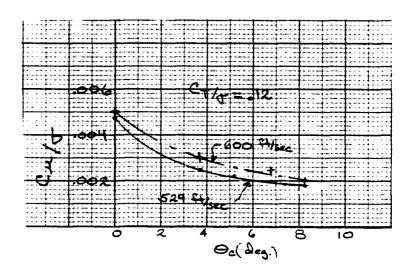
The difference in FM $_{T}$ for 6.75° and 8.3° is small as shown below: In addition, the relationship of FM $_{T}$ and θ for 600 ft/sec does not agree with that of the other 3 V_{T} .



4.1.3 $\frac{CT}{\sigma}$ vs $\frac{C\mu}{\sigma}$

As plotted below for a given σ , the benefit from θ diminishes above 4°. Below 46 the effect of blade angle is twice as great as that above 4°.





4.1.5 $\frac{CT}{\sigma}$ vs $\frac{C_{P_1}}{\sigma}$

This relationship is basically the same for all V_T 's tested. Therefore the variation in C_{PT} vs. V_T is primarily dependent on C_{PC} .

 $\frac{\text{CT}}{\sigma} \text{ vs } \frac{\text{C}_{\text{PO}}}{\sigma}$

See comments for $\frac{CT}{\sigma}$ vs $\frac{C\mu}{\sigma}$. For C_{PC} < .004 relationship is virtually independent of V_T .

The curve experiences a slope change above 1.7 BPR. The mach number of the slot velocity approaches 1.0 at this point.

4.1.13 T vs BPR

This curve also indicates a slope change at BPR 1.7. At this level the flow is sonic at the slot exit and the coanda effect is degraded. The slot height to chord ratios are greater than .004 for the inboard portion of the blade also indicative of a degraded coanda affect.



4.1.20

T vs θ_c

Thrust appears to peak at 6-7° for the high BPR case but closer examination of the data indicates that the BPR was decreased at this point because the shaft torque was approaching 160,000 in-lb limit.



Cruise 4 Correlation

Figure No.	<u>Parameters</u>	
4.1.1	$FM_{\overline{T}}$ vs $\frac{C_{\overline{T}}}{\sigma}$	Predicts shape of curve but under- estimates the magnitude.
4.1.3	CT vs Cμ σ σ	Curve shape is good but magnitude is underestimated at low θ . At high θ , program underestimates CT for the higher $C\mu$, but shows σ $C\mu$ good correlation at lower σ .
4.1.5	$\frac{CT}{\sigma}$ vs $\frac{C_{PS}}{\sigma}$	Excellent correlation.
4.1.7	HP _s vs T	Excellent correlation except at higher thrust levels where the program underestimates the power required.
4.1.12	m vs BPR	Good correlation below 1.6 BPR. Program does not predict the slope change above 1.7 BPR where the exit flow goes sonic.
4.1.13	T vs BPR	Trending is good. Magnitude is underestimated for 0°, 3.9°, excellent for 6.75° and overestimated for 8.3°. Slope change above 1.7 BPR is not predicted.

CCHAP Correlation

Figure No.	Parameters	
4.1.2	FM_s vs $\frac{CT}{\sigma}$	Predicts shape of curve but underestimates magnitude.
4.1.3	CT vs Cμ σ σ	Predicts shape of data and shows good correlation at higher θ but underestimates the lower θ_{C} curves.



4.1.5	CT vs C _{PS}	Excellent correlation except slightly underestimates 0° curve.
4.1.7	HP _s vs T	Good correlation except, over- estimates power required.
4.1.12	m vs BPR	Excellent correlation except the slope change above 1.7 BPR is not predicted.
4.1.13	T vs BPR	Good correlation except for thrust overestimated for 8.3°.

4.1.2 Pneumatic Response

The total pressure distribution in Blade #1 versus blade radius is presented in Figures 4.1.21 A to D.

Slot stiffness of blade #1 (S/N 1002) is plotted in Figure 4.1.22a for various blade radial stations. The slot is softer than the 1979 data but indicates the same change (trend) with radius as the previous data. The slot bias is plotted in Figure 4.1.22b. The individual blade station pressure/deflection data is plotted in Figures 4.1.23 to 4.1.27. Note in Figure 4.1.27 the data indicates a changing zero reference with small deviations in slope.

4.1.3 Blade Bending Response

Blade #1 flap bending response is presented in Figure 4.1.28. The corresponding chord bending response is presented in Figure 4.1.29. Both plots are from data at 600 ft/sec. $V_{\mbox{TIP}}$.



4.2 Vibration and Acoustics

The typical frequency signature of the following parameters is presented as follows:

Parameter	Figure No.
Flap Bending @ Blade #3 Cuff	4.2.1
Chord Bending @ Blade #3 Cuff	4.2.2
Torsion @ Blade #1 .18R	4.2.3
Slot Deflection @ .59R	4.2.4
Pitch Link Load @ Blade #1	4.2.5

As evidenced by Figure 4.2.1 the blade flapping is primarily a 2P waveform with peak at nose and tail crossings. First natural flap mode is suppressed while second flap mode does show up near 45 hz.

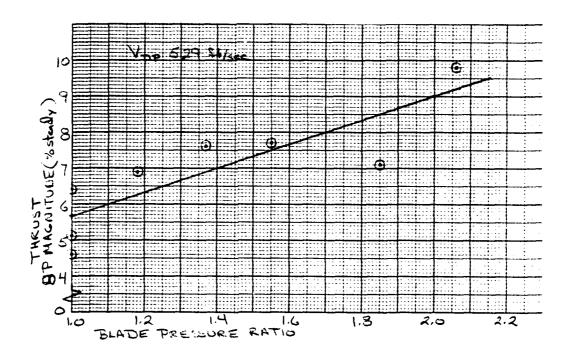
The strong 4P signal in chord bending in Figure 4.2.2 is an amplification caused by the first natural chord mode.

Torsional spectrum shows the same 2P characteristic as flapping. Slot deflection peaks are strictly related to rotor harmonics. Pitch link spectrum looks like the flapping except the first as well as the second natural flapping mode is evident.

Even though pitch and roll moments were not balanced out, the torque vibratory level does not exceed 10% of the median as shown in Figures 4.2.6.

Vibratory pressure levels in the plenum are also less than 10% of the median as shown in Figure 4.2.7.

Vibratory thrust levels are plotted in Figure 4.2.8 as a percent of the median. The vibratory levels reach 30% of the median at low thrust levels, but are generally constant at ±1200 lb throughout the thrust range. The harmonic content of the thrust signal is presented in Figure 4.2.9. The 8P signal is predominant and is caused by 8 valve azimuthal configuration. As shown in Figure 4.2.9, the trend is independent of thrust. Note the significant difference in the three 3000 lb. spectra. In fact, the 8P magnitude varies linearly with blade pressure ratio as indicated below:



As noted above, the plenum pressure fluctuations are small and not the cause of this vibration. This n valve per rev phenomenum was also seen in the tests involving the Sikorsky plenum design, a 32P (valve) plenum, see Reference 2.2.5. This vertical vibration, $\pm .2$ g's at a CT/ σ of .12, is a serious concern both for pilot comfort and for structural fatigue considerations.

The acoustic data was not available at the time of report.



4.3 Balance Efforts

A chronological summary of the balance corrections attempted is given in Table 4.3.1. Four different techniques were employed:

- Blade inlet duct area reduction
- 2. Differential blade angle changes
- 3. Partial trailing edge taping
- 4. Tip weight changes

The last technique was terminated following excessive vibration in the test stand. The results of the other three techniques are discussed in the following sections.

The 1P (the only controllable harmonic) pitch unbalance correction is followed sequentially in Figures 4.3.1 for typical low thrust and 4.3.2 for high thrust conditions. Figure 4.3.1 indicates very little change in pitch unbalance due to root duct area changes for nonblowing conditions (RPO1.0). Dynamic mechanical rotor balance could thrus be conducted with little concern for the secondary effects of centrifugal pumping with pneumatically mismatched blades.

The most significant balance change was caused by blade angle changes (Config. 14, 15). The unbalance vector showed a definite shift to the changed blade (#1).

High blowing and low blowing (or no blowing) conditions correlated well as to vector direction, with the magnitude of the unbalance significantly increased as blowing increased.

The spectrum to the eighth harmonic of pitch is presented in Figure 4.3.3 for the initial runs, and in Figures 4.3.4 and 4.3.5 just prior to the performance runs. The spectra show similar characteristics:

- 1P and 4P are most significant harmonics (as expected)
- Magnitude is primarily dependent on rotor loading (Ct/ σ), less dependent on method of achieving the thrust level (high θ_C vs high RPO)

The 1P reduction between initial (Figure 4.3.3) and final (Figure 4.3.4) configurations was roughly 30%. Comparison of Figures 4.3.4 and 4.3.5 shows generally higher unbalance with higher tip speed.

Typical time histories for pitch and roll are presented in Figures 4.3.7 and 4.3.8.

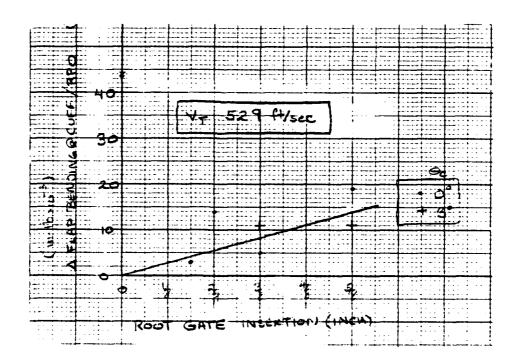


The rotating offset that appears as the pitch and roll 1P is due to a difference in lift on opposing blades. This difference can be seen in the blade cuff flap bending time histories of Figure 4.3.9. The blade to blade differences in flap bending (@ cuff) response are plotted in Figure 4.3.10a versus blade collective pitch, and in Figure 4.3.10b versus plenum pressure ratio. This data corresponds to the performance configuration (10) of Table 4.3.1. As indicated in Figure 4.3.10a the pairing of blades 1 and 3, and 2 and 4 opposite each on the rotorhead was designed to minimize the blade angle response differences (and thus the unbalance) in the rotorhead. Figure 4.3.10b indicates that blade 4 was still pneumatically different from the other three blades after the balance effort. This is further confirmed by the phase of the unbalance vector of Figures 4.3.1 and 4.3.2 lying primarily along the blade 2 and 4 axis.

4.3.1 Duct Area Reduction

CARCUMAL TRANSPORTATION OF STREET

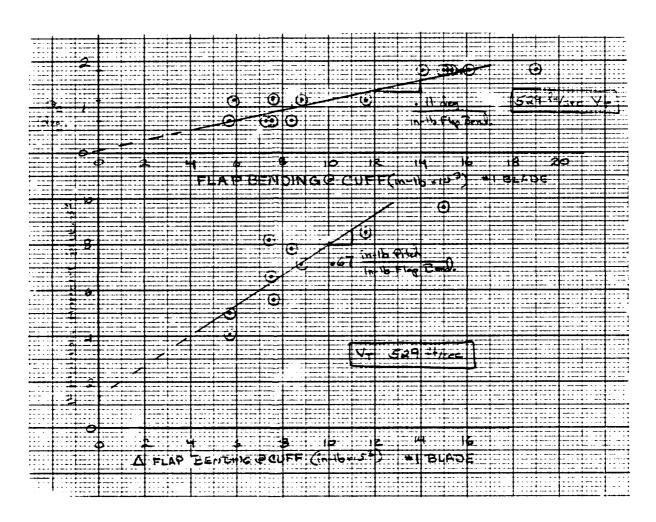
Area changes to the inlet duct were made on blades #3 and #4 during this testing. The effect on cuff flap bending/plenum pressure ratio is plotted below versus root gate position.





4.3.2 Blade Angle Changes

Blade angle changes, relative to the other three blades were made to Blade #1 during this testing. The effect of these changes on cuff flap bending are plotted below. The effect of a change in cuff flap bending for a single blade on the rotor balance, 1P head moment, is also shown below.



4.3.3 Partial Trailing Edge Taping

Blade trailing edge #1 was taped closed from root to .435 radius to evaluate this change on the blade performance and thus the rotor performance. The effect on total pressure in the blade is shown in



Figure 4.1.21A where the change is to minimize the pressure drop between the plenum and the blade root. The effect on blade bending radial distribution is shown in Figures 4.3.11 and 4.3.12. There is no consistant trend in thrust or torque. The chord bending is unchanged, while the flap bending indicates increased bending outboard.



4.4 Miscellaneous Effects

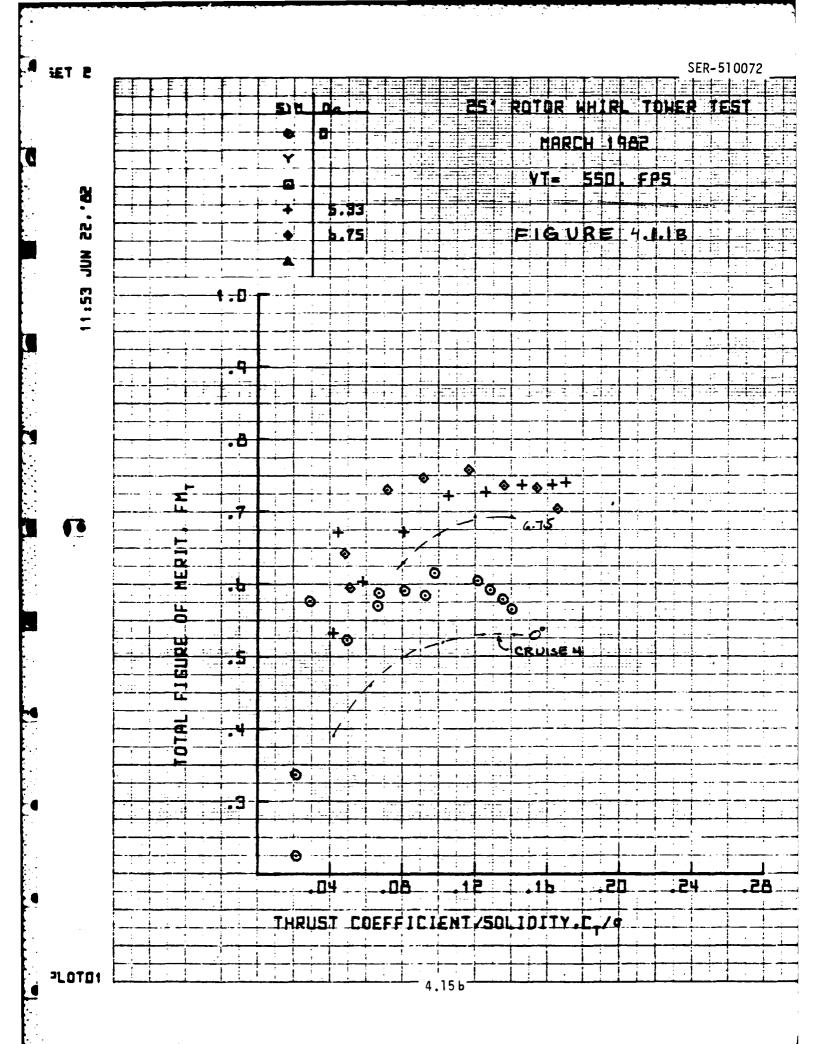
The effects of configuration changes to the tip caps and to the leading edges of the blades are evaluated here.

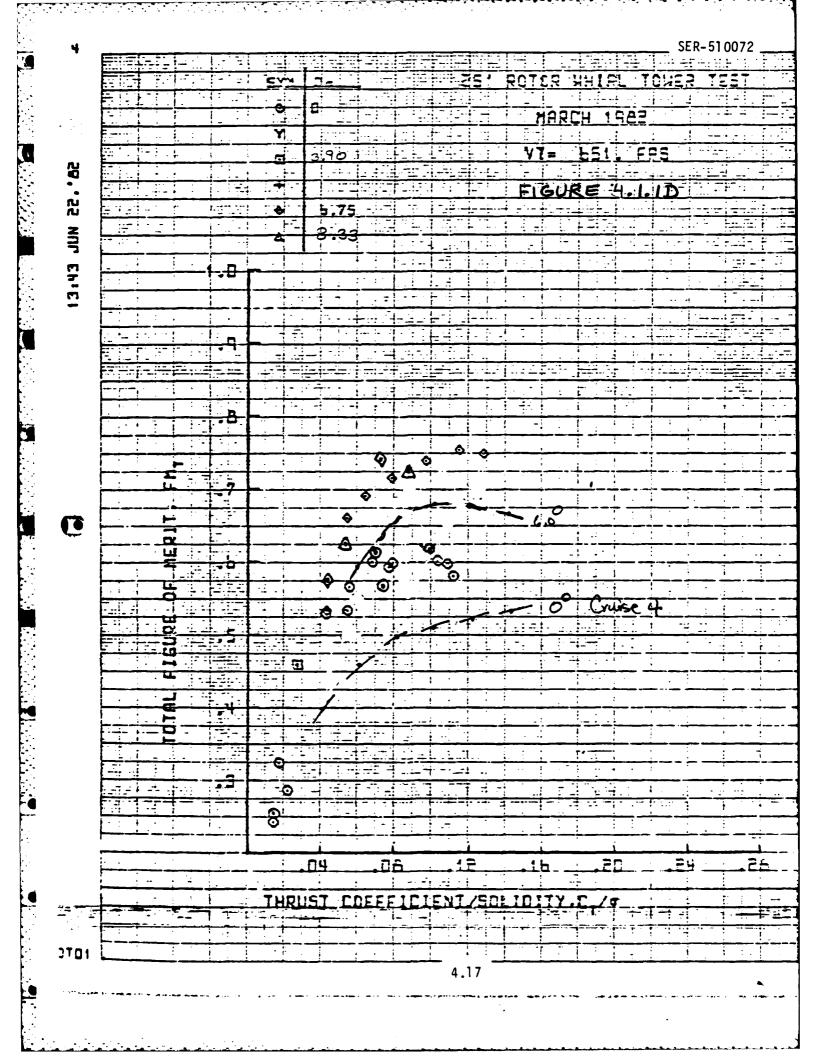
4.4.1 Blown Tips

The comparison plots with and without blown tips are presented in Figures 4.4.1A to 4.4.15A. For a given CT/σ the blown tip shaft figure of merit is typically 105% of the unblown level as shown in Figure 4.4.2. However for a given CT/σ the total blown figure of merit is 94% of the unblown level (see Figure 4.4.1). In the blown tip configuration the rotor needs less shaft power but more compressor power to produce the same lift as in the unblown configuration. The cost of the blown tip is the weight flow diverted from the lift producing slot to the drag reducing tip. For a thrust coefficient of .12 the delta decrease (.001) in shaft power coefficient of the blown tip, see Figure 4.4.5, equals delta increase in compressor power coefficient of Figure 4.4.6. Thus there is no difference in the thrust coefficient/total power coefficient relationship of Figure 4.4.4.

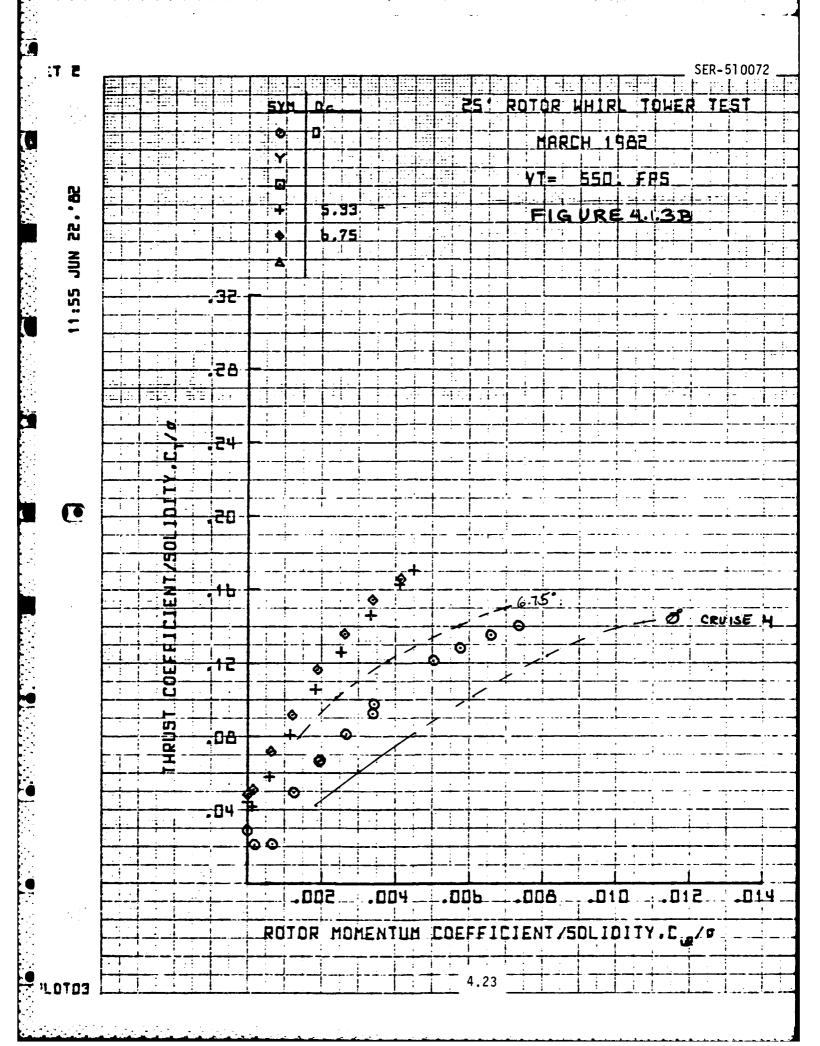
4.4.2 Leading Edge Taping

The comparison plots with and without the leading edges taped as presented in Figures 4.4.16 to 4.4.23. All plotted data were obtained at 529 ft/sec tip speed, however data exist for 600 ft/sec as well. Drag is reduced as evidenced by shaft figure of merit vs CT/ σ , plot 4.4.17, and shaft torque vs thrust, plot 4.4.22. In Figure 4.4.17, the taped figure of merit is typically 110% of the untaped level for 0° θ and 104% of the untaped for 6.75° θ . Similarly in Figure 4.4.22 for a given thrust level, the taped shaft torque is 85% of the untaped torque for 0° θ and 95% of the untaped torque for 6.75 θ . The weight flow is roughly the same for both configurations indicating that the benefit is not derived from reduced leakage out the leading edge.





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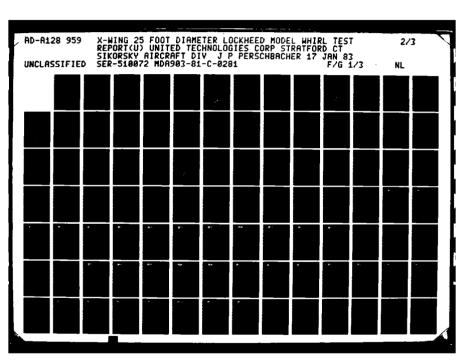
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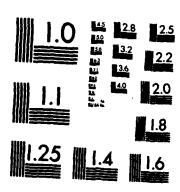
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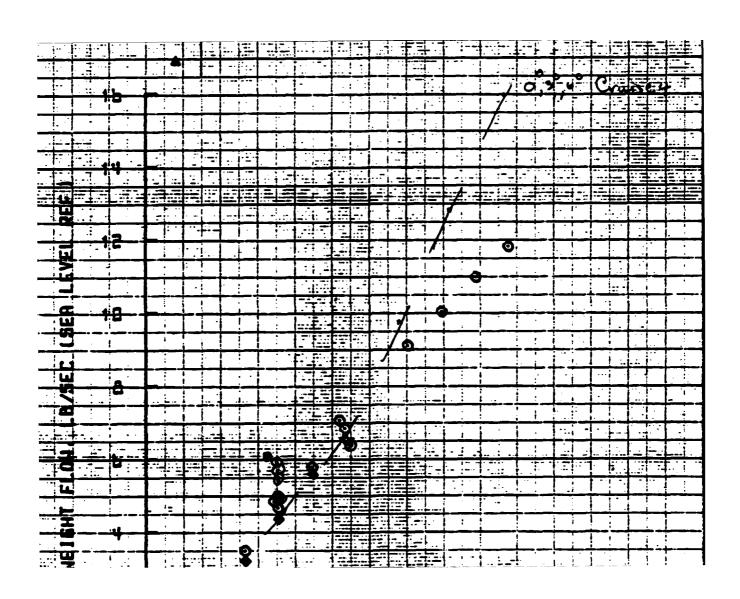
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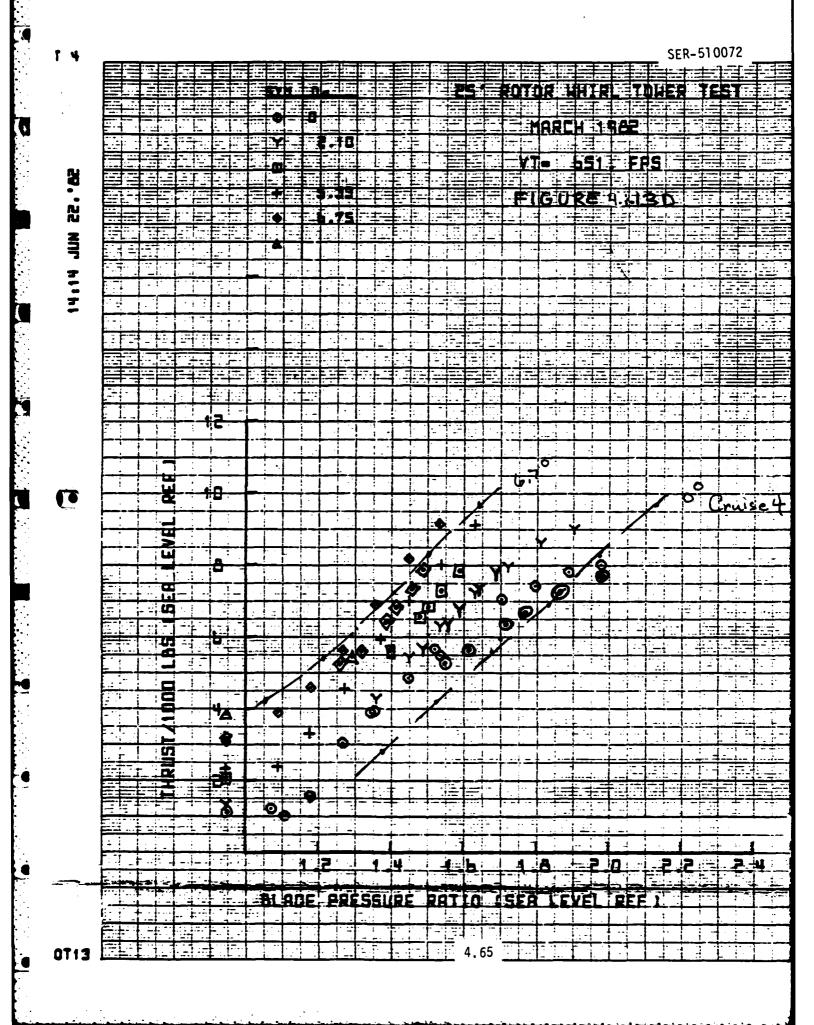
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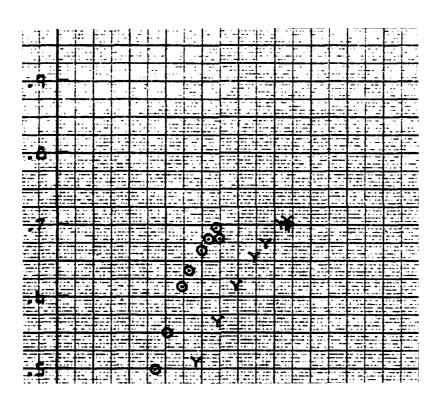
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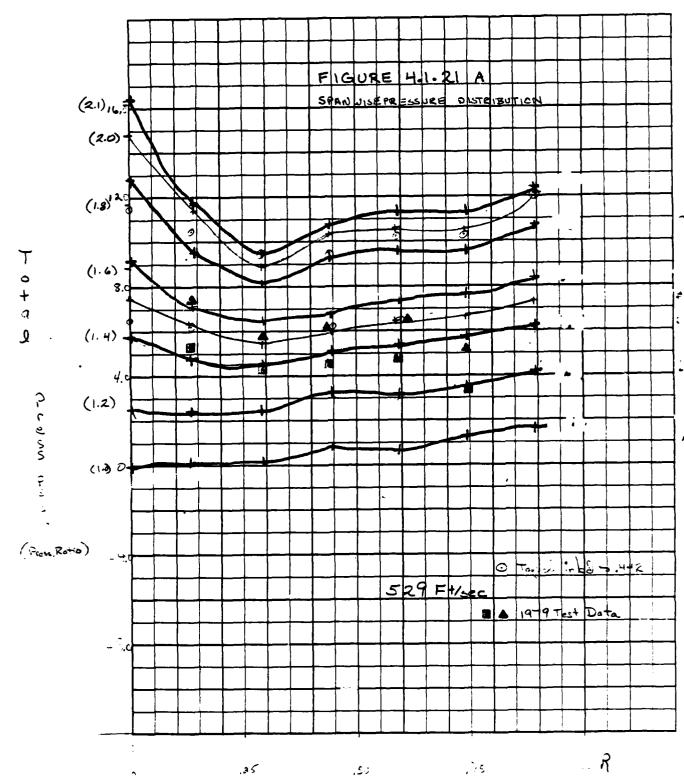
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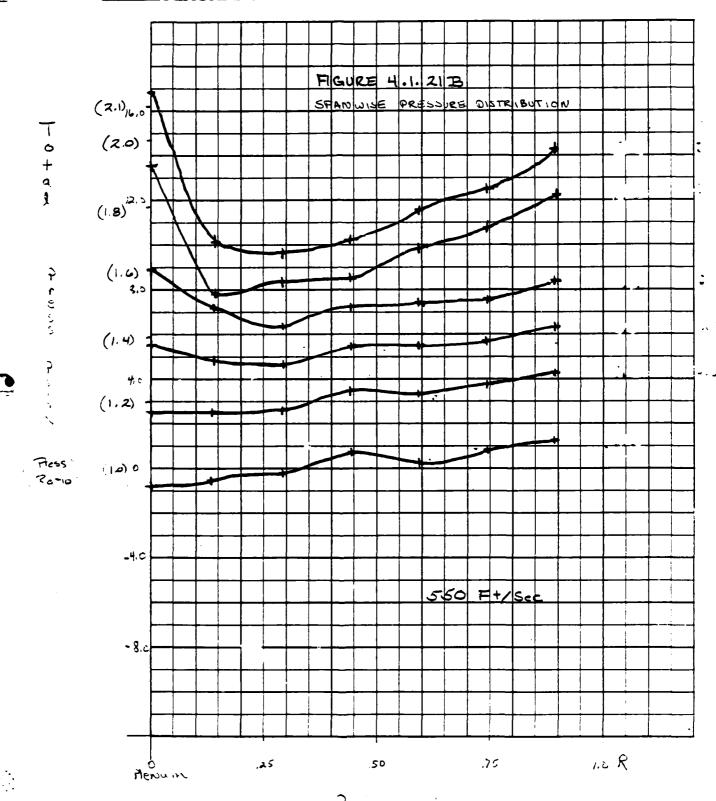
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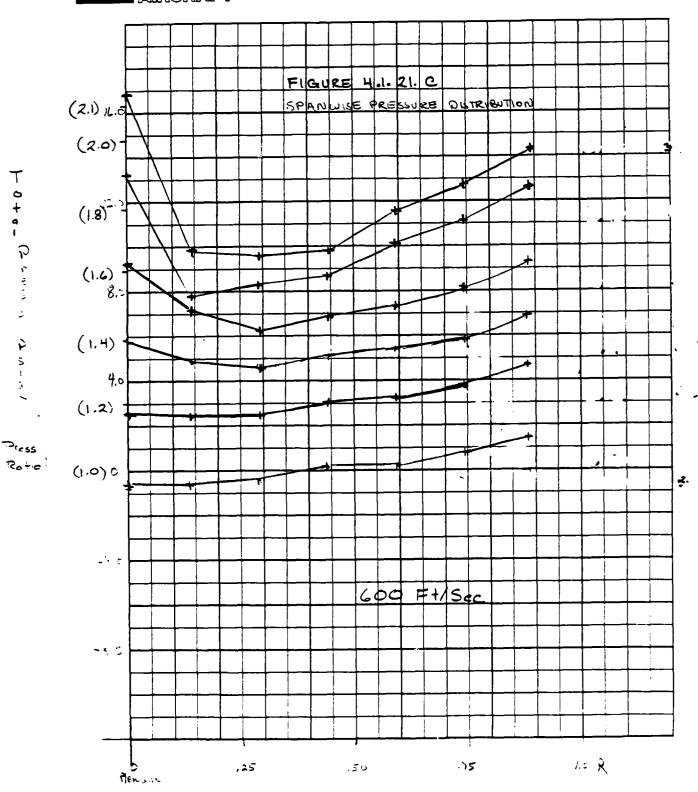
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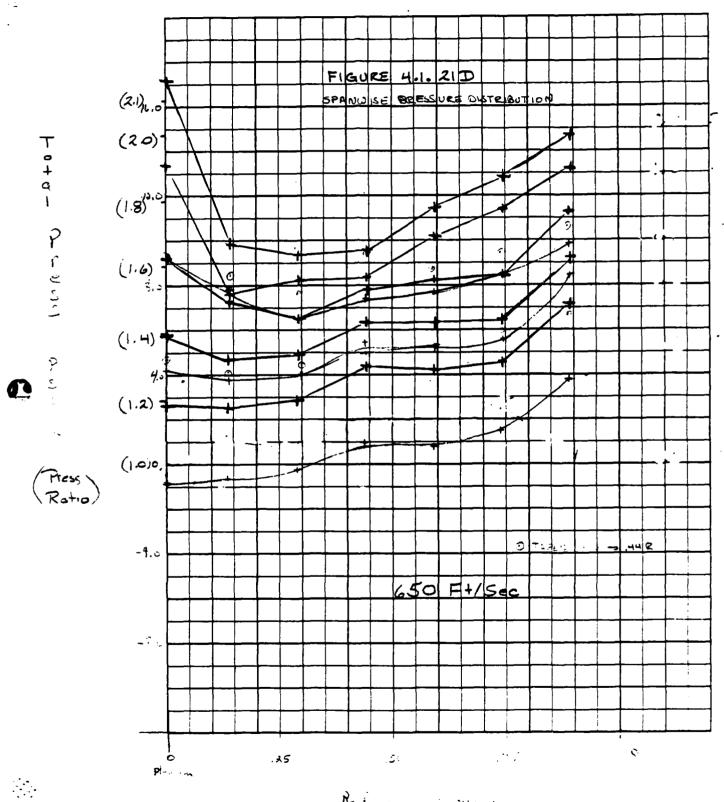
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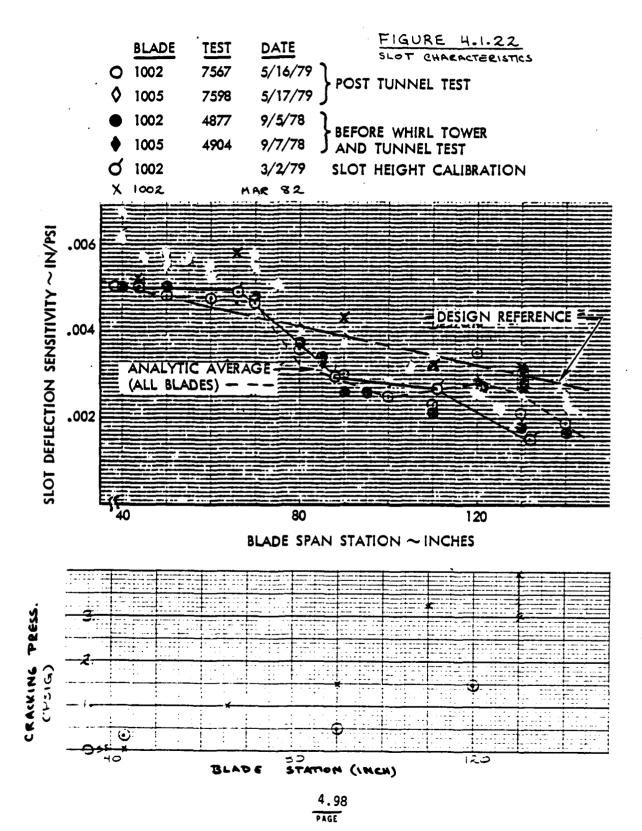
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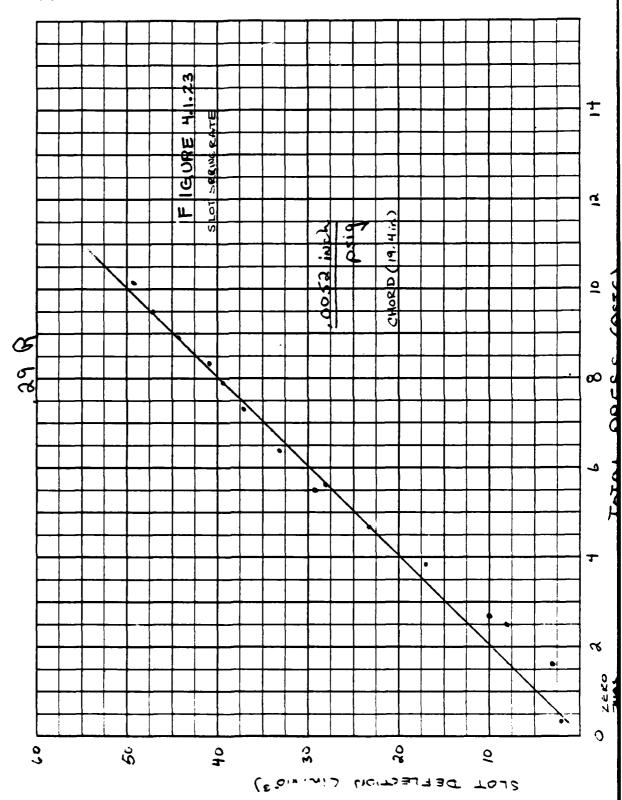


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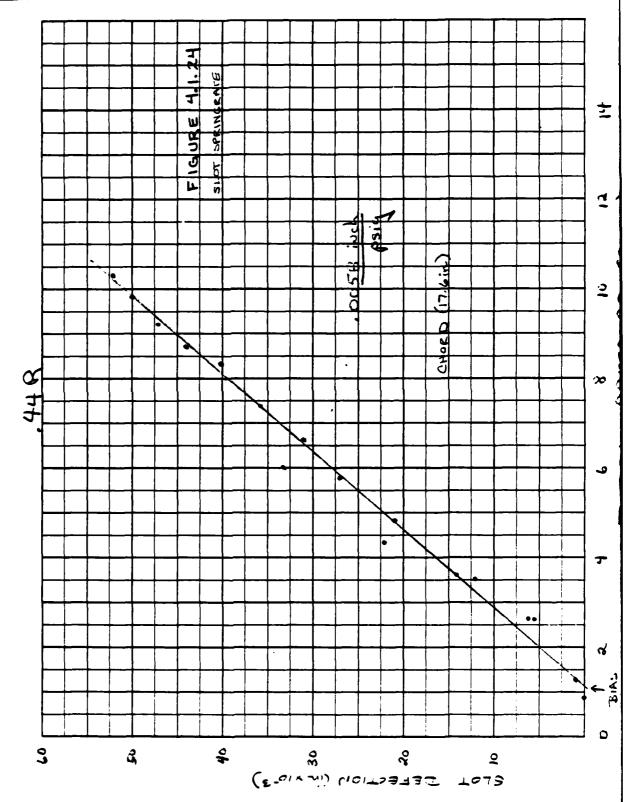
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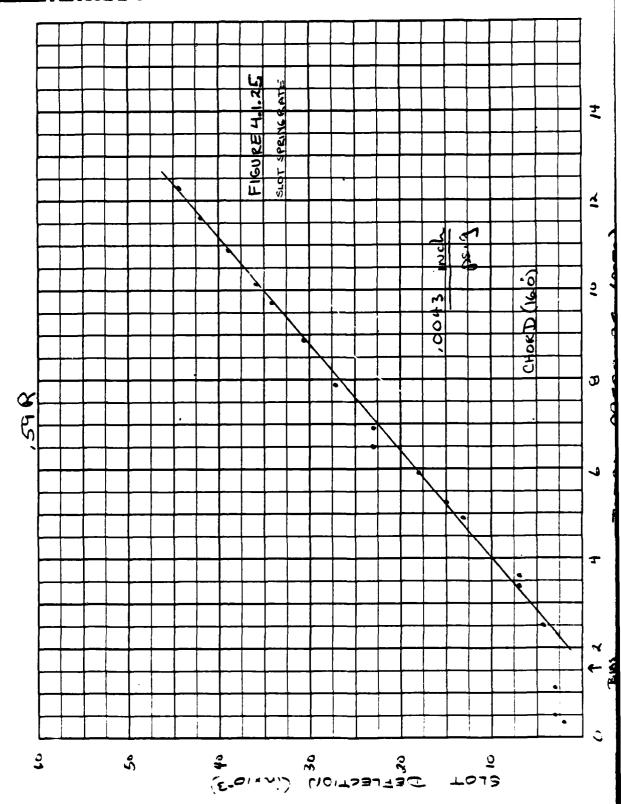


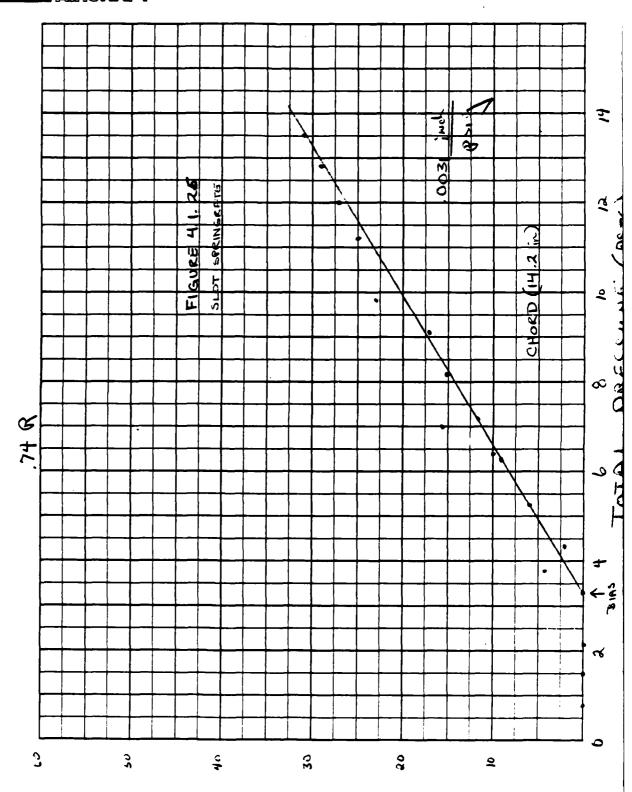


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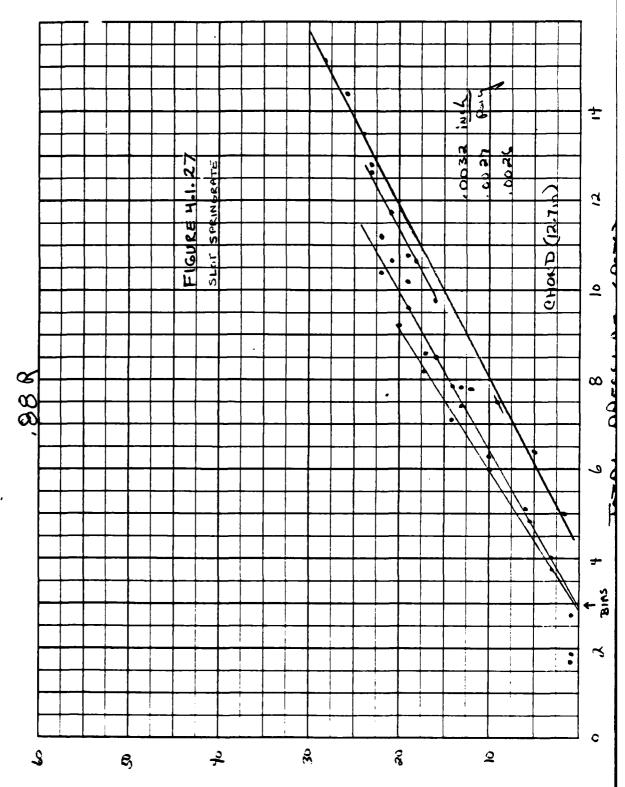




SLOT DEFLECTION (mxm2)

PAGE 4.162

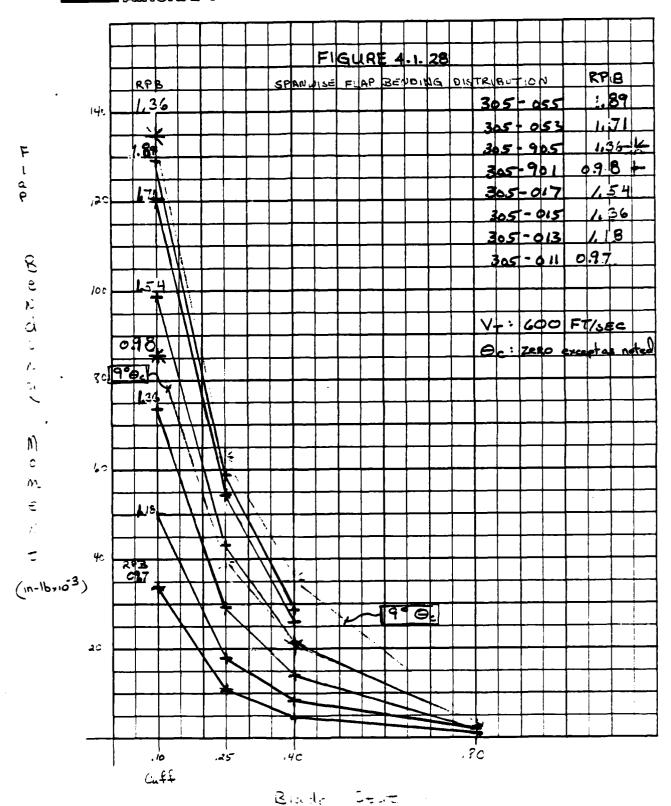
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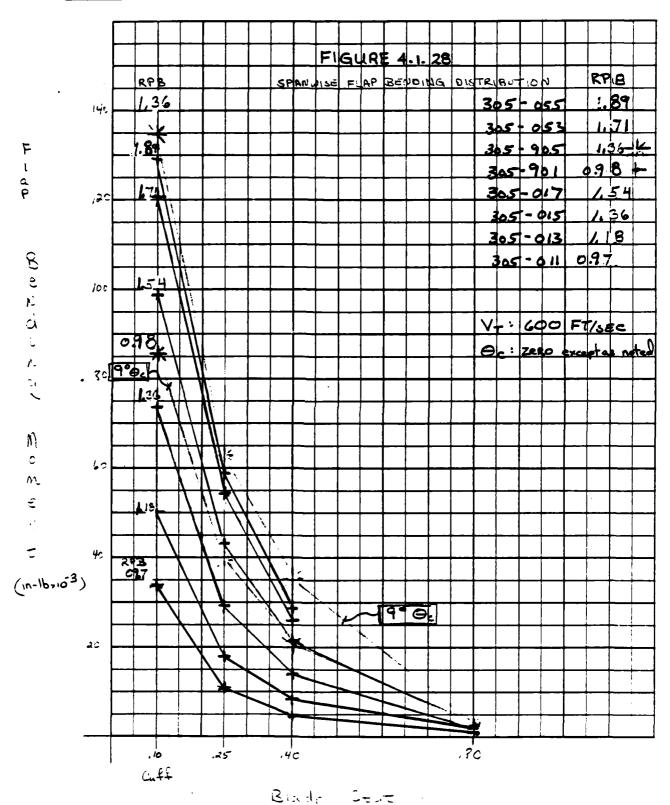
SLOT DEFLECTION (in x 10 3)

**AGE 4.103

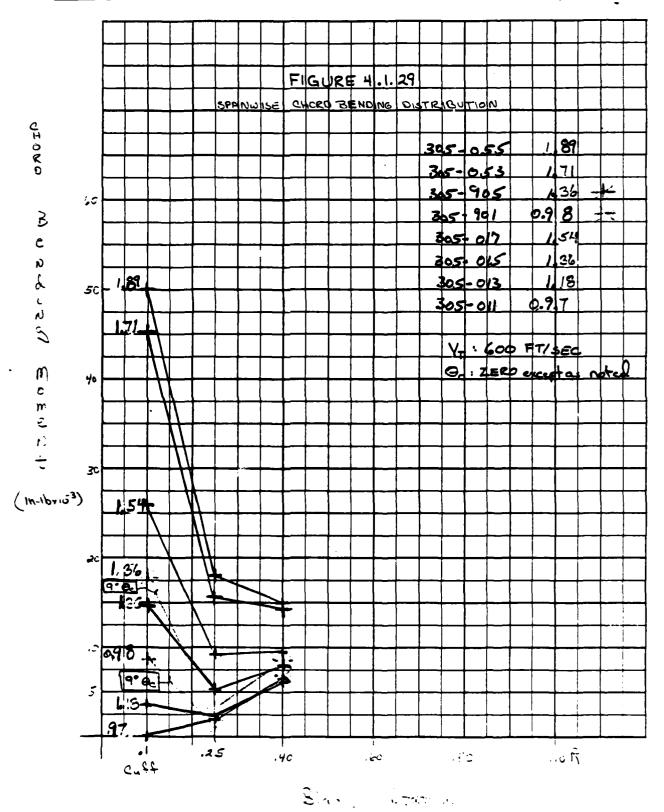
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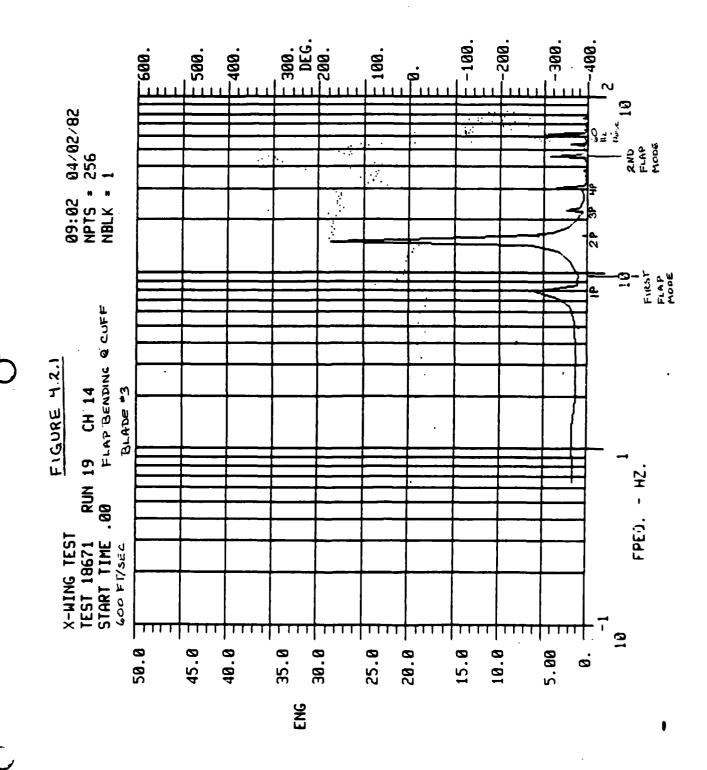


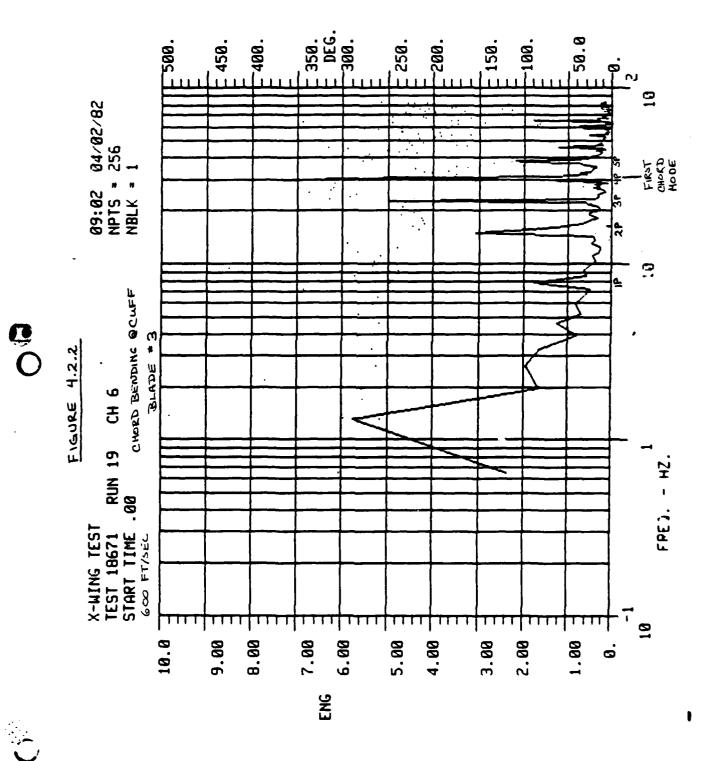
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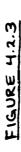


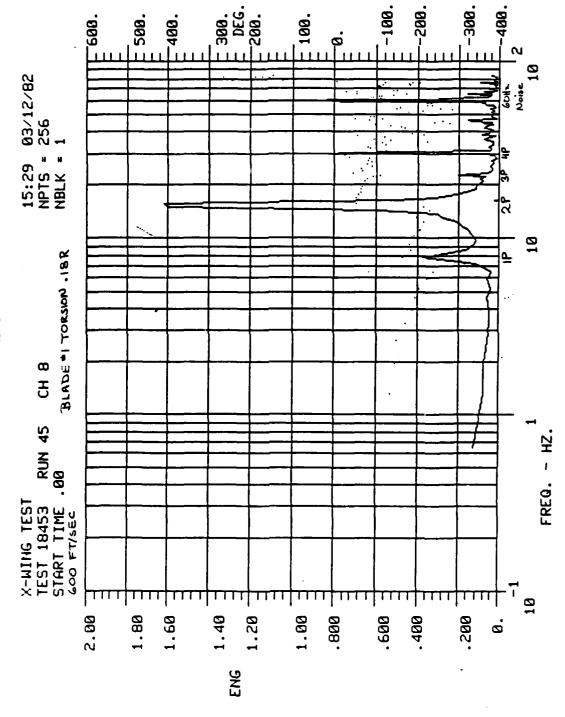
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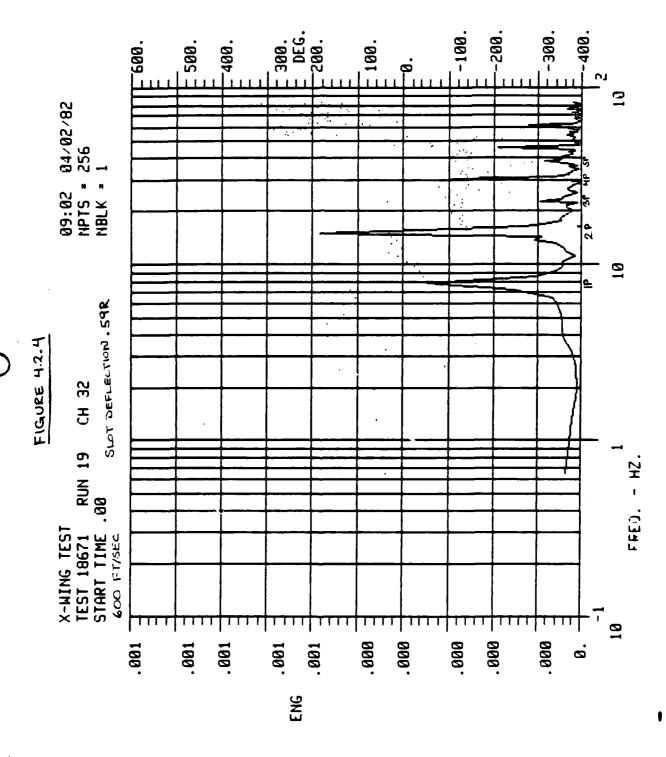




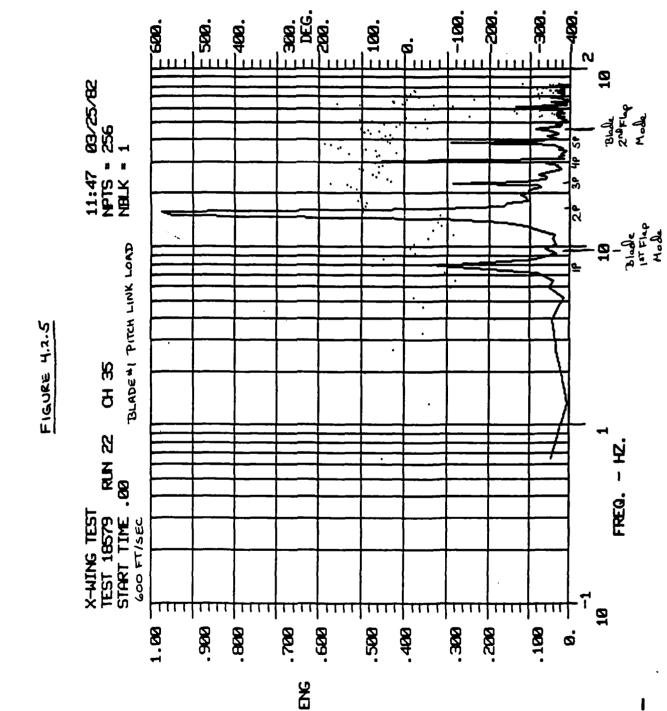




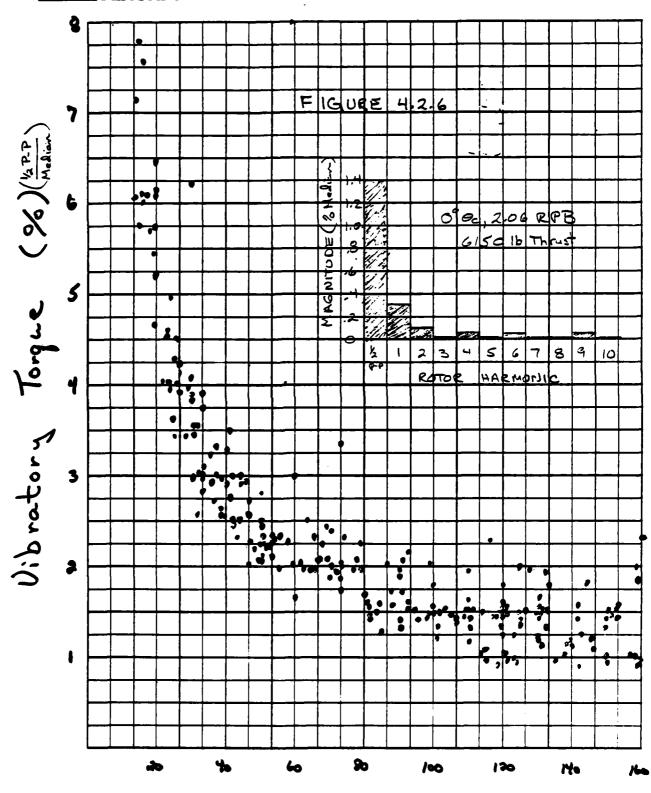




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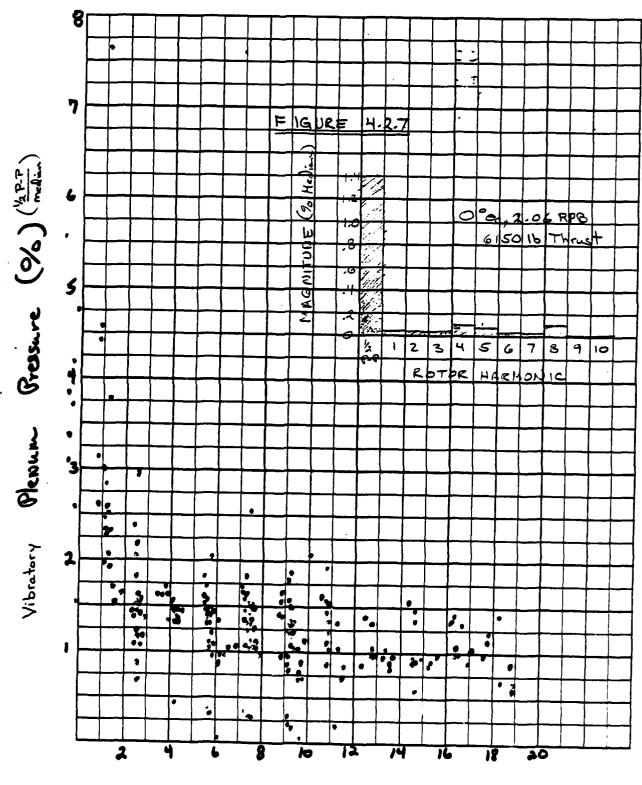


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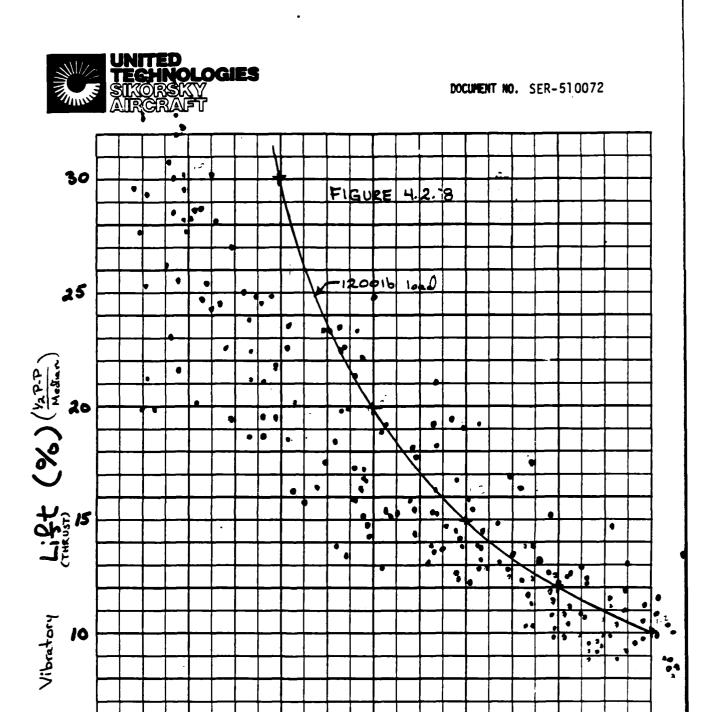
Median Sheft Torque #2 (1n-16x103)
4.777

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Median Plenum Pressure (psis)

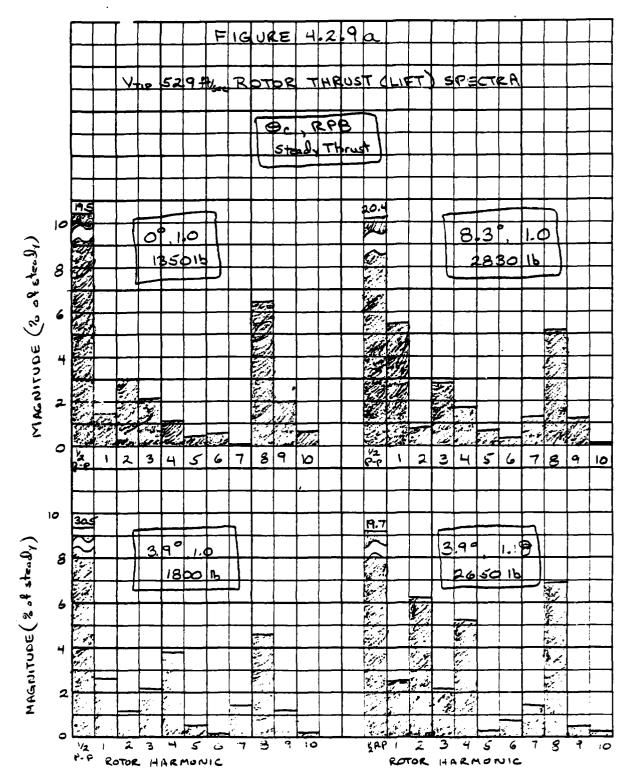
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Median Lift #2 (16 × 103) pressure toure

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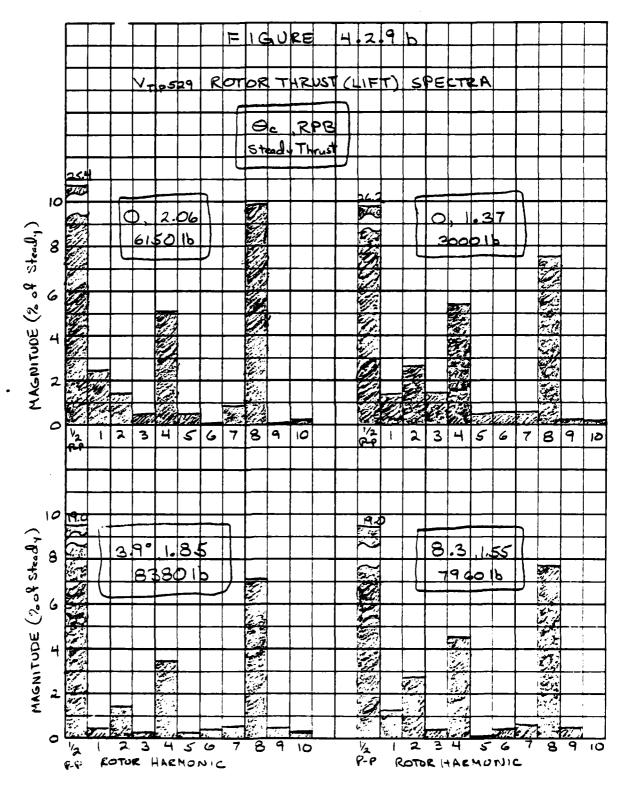




TABLE 4.3.1

Balance Changes

Configuration No.	Change from Previous Configuration
1	Baseline
2	#3 Blade rootgate inserted 3/8"
3,4,5	#3 Blade rootgate inserted 1/4"
6,7	Leading edge taped, all blades
8	#3 Blade root gate withdrawn 1/4" (Similar to Config. #2 except for taping)
9	#4 Blade rootgate inserted 3/8"
10,11	#4 Blade rootgate withdrawn 3/16", Hover Performance Configuration
12	No tip blowing, all blades
13	<pre>#1 Blade trailing edge taped to .44R, tip blowing reinstated</pre>
14	#1 Blade angle decreased 1° 10', tape emoved
15	#1 Blade angle decreased 40'
16	<pre>#1 Blade restored to configuration 10,11 condition</pre>



Figure 4.3.1

Sequential 1P Pitching Moment (in-1b \times 10⁻³) Unbalance Polar Plot (Low Thrust)

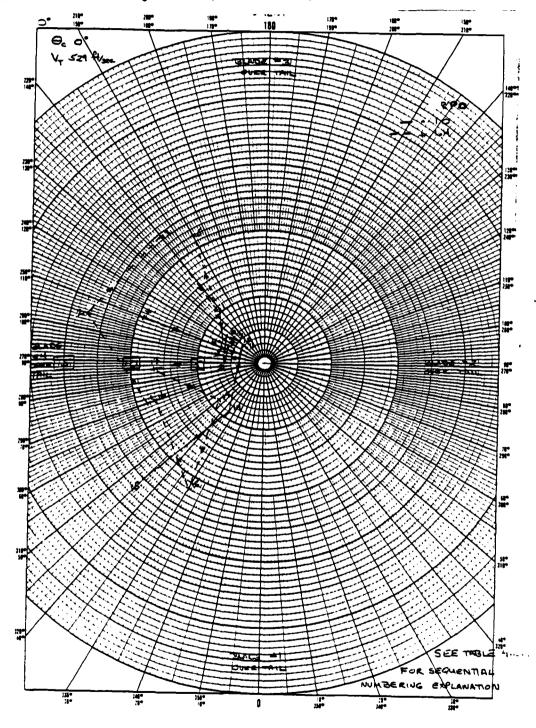
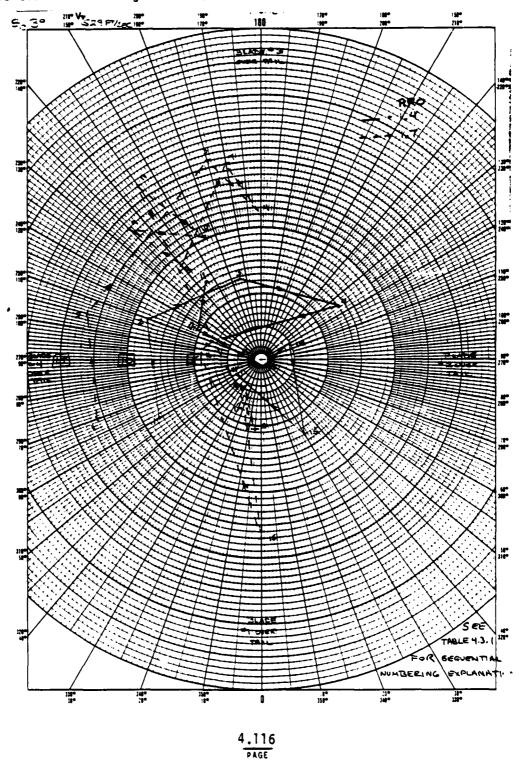
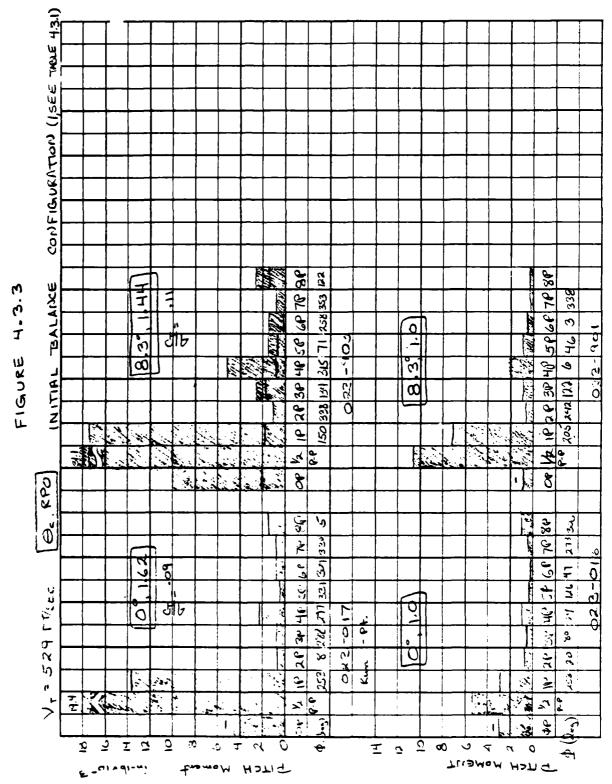




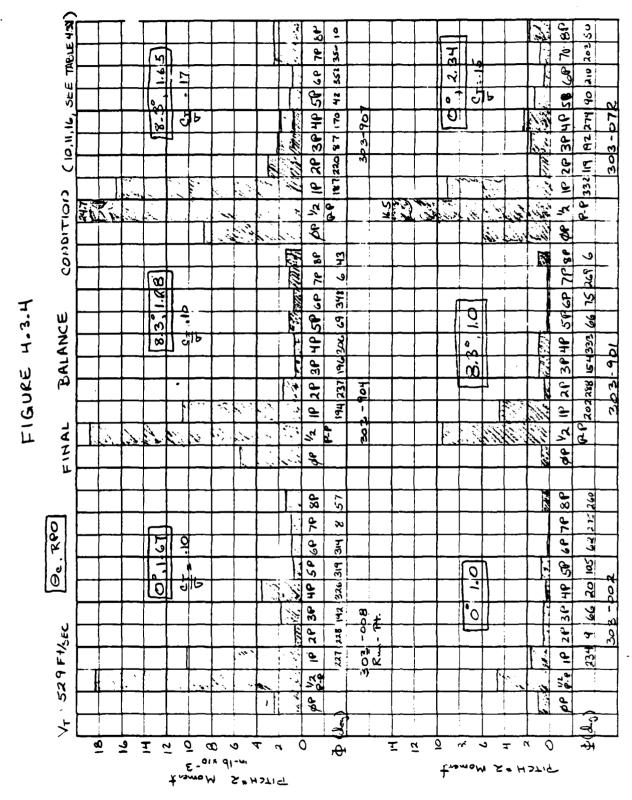
Figure 3.4.2

Sequential 1P Pitching Moment (in-1b \times 10⁻³) Unbalance Polar Plot (High Thrust)

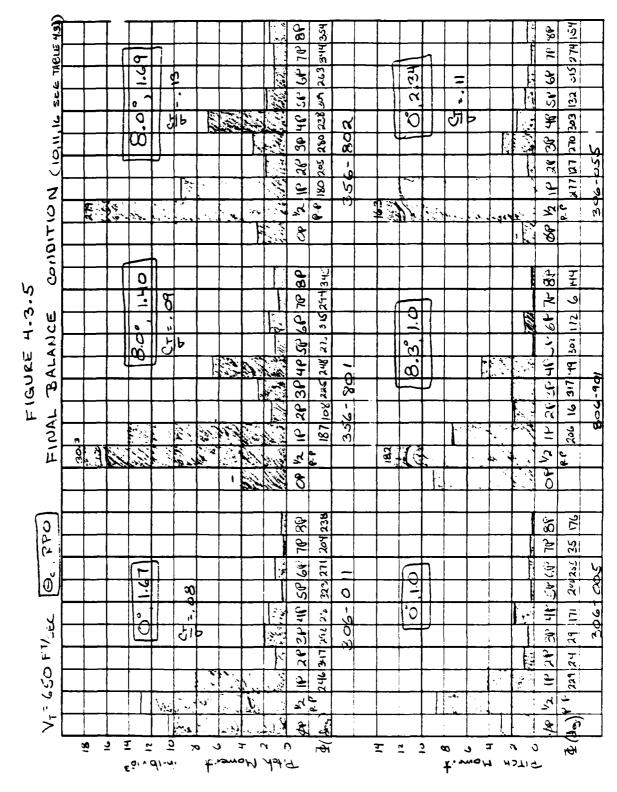




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4.118 PAGE



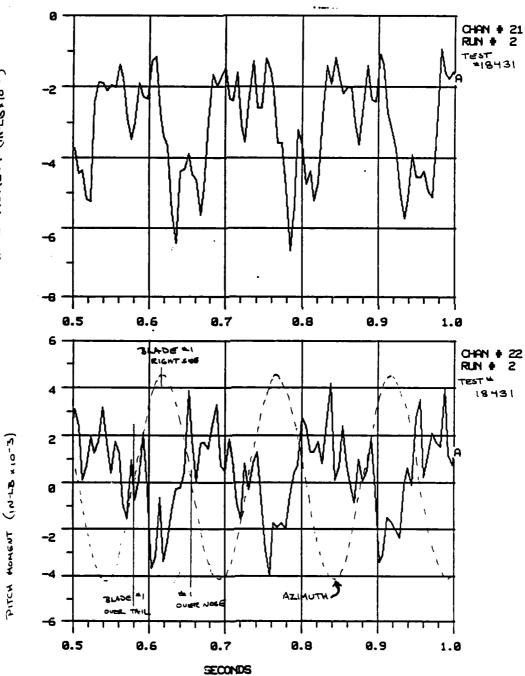


MOMENT (IN-LB + 10-3)

FIGURE 4.3.7a

ROLL/PITCH MOMENT TIME HISTORIES

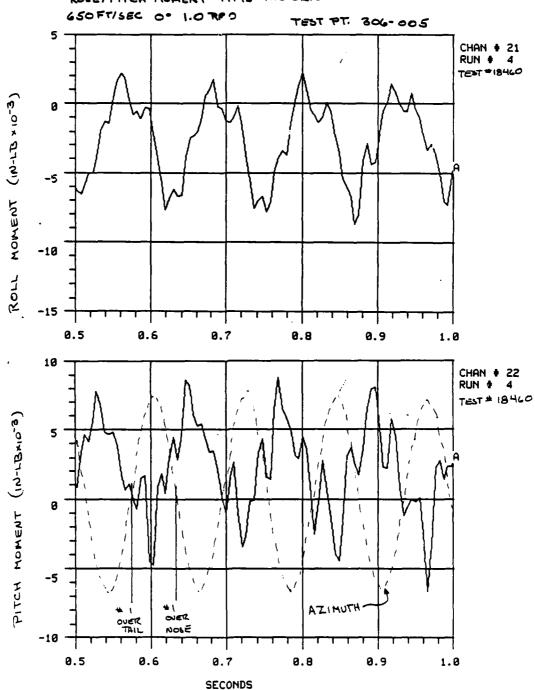




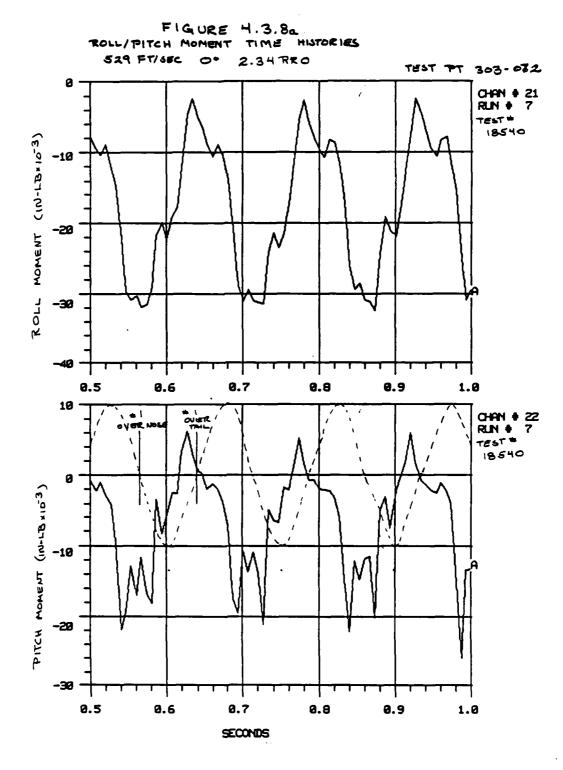
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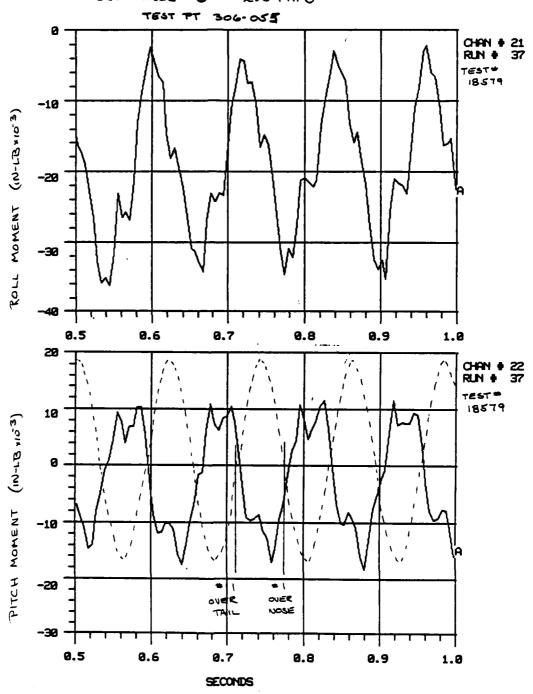
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FIGURE 4.3.86

ROLL/PITCH MOMENT TIME HISTORIES
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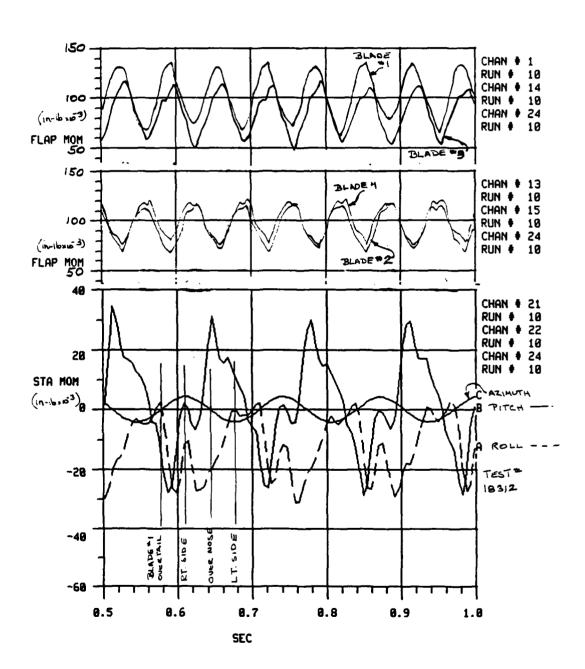


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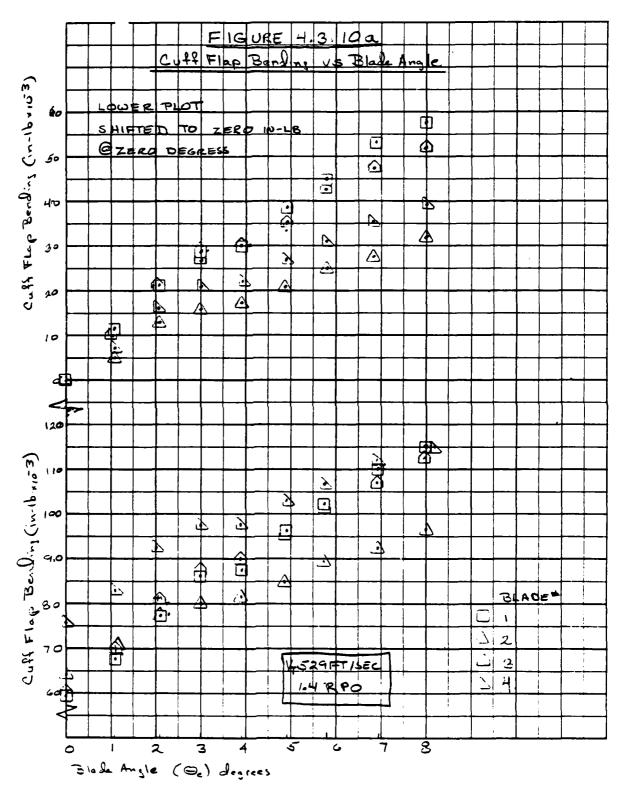
FIGURE 4.3.9

BLADE ROOT FLAP MOMENTS & ROLL/PITCH MOMENT TIME HISTORIES

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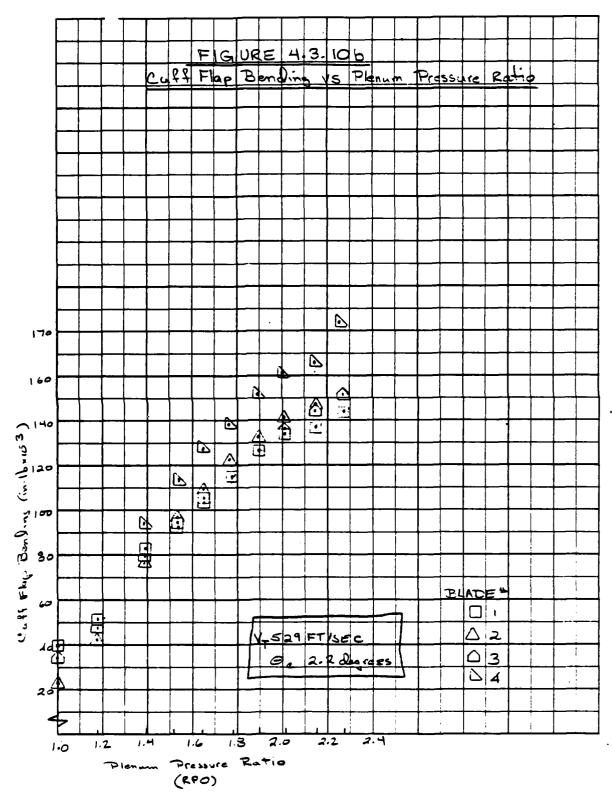


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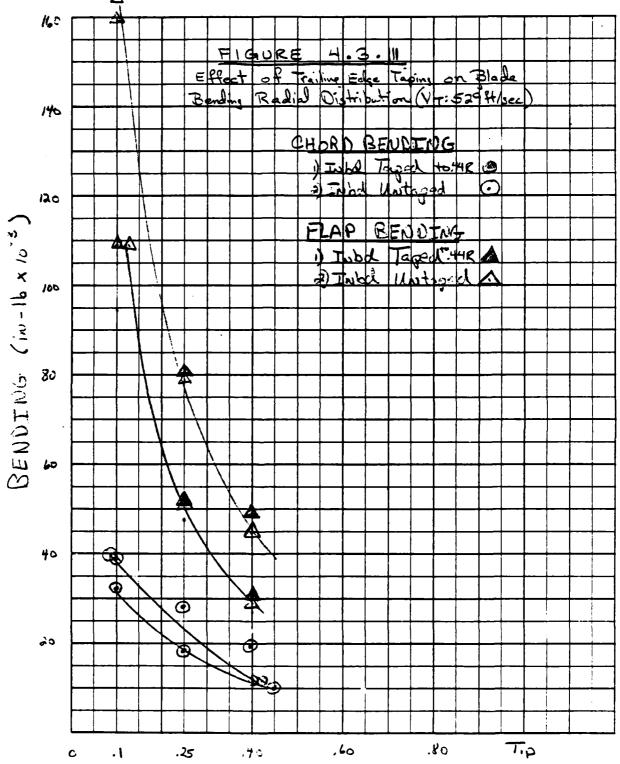
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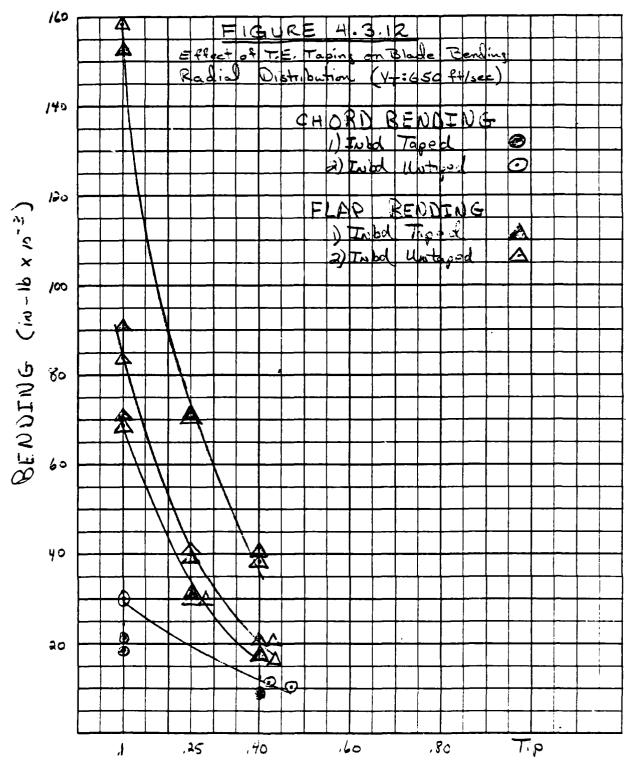
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BLADE RADIUS

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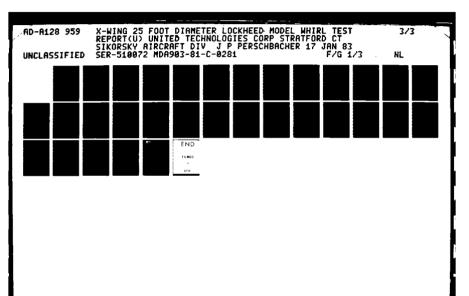
SER-510072 ET 7 MARCH 1982 OPENED 529 16:35 JUN 22. '62 FIGURE 4.4.2A . 0 i-.9 . 0 Y 7 0 REP. 0 . b SHAF. ПH AD. 20 COEFFICIENT/SOLIDITY 4.130 2010Z

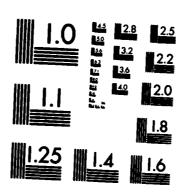
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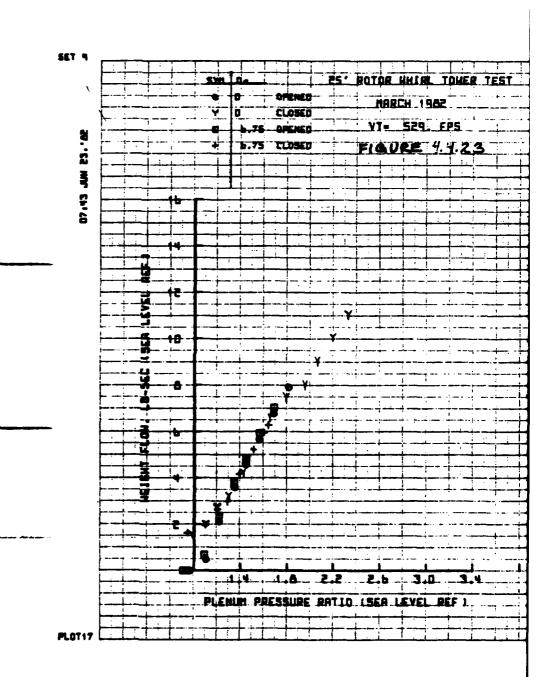
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5.0 CONCLUSIONS AND RECOMMENDATIONS

- A. The X-wing concept as embodied by the Lockheed 25 foot diameter rotor model demonstrated an expanded envelope with CT/σ levels to .18, tip speeds to 650 ft/sec., collective blade angles to +8.3 degrees, and blade pressure ratios to 2.06. The following is noted:
 - 1. The benefit of collective pitch in reducing blowing requirements is non-linear and is reduced significantly above 4°.
 - 2. At blade pressure ratios above 1.7, the thrust/blowing slope decreases because the slot exit velocity nears sonic.
 - 3. The benefit (decreased shaft power) of blown tips is matched by the additional flow requirements (increased compressor power).
 - 4. Taped (physically closed) leading edge slots reduce the shaft power requirements by 5%.
 - 5. Both CRUISE 4 and CCHAP programs show good correlation with parameters not heavily influenced by pneumatics. The programs predict the trends of the pneumatic data, but underestimate the magnitudes.
- B. Track and balance efforts on the X-wing are necessarily more complex than that of a standard rotor because of the additional variable: pneumatics. Correspondingly, provision should be made in the design for a tool (such as a root flow gate or variable stiffness slot) to independently control blade pneumatics without affecting the basic blade characteristics: airfoil shape and weight/stiffness distribution.
- C. Control power with the plenum valves nominally 80% open was insufficient to permit investigation of the control system response.
- D. Vibratory thrust levels at the η (valve) per rev frequency are significant and need to be considered from a ride comfort standpoint and also from a structural standpoint.